Approaches to evaluation of research and development in agriculture: a case study of rice productivity in Thailand 1967-1998

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APPROACHES TO EVALUATION OF RESEARCH AND DEVELOPMENT IN AGRICULTURE: A CASE STUDY OF RICE PRODUCTIVITY IN THAILAND 1967-1998

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AUTHOR'S CERTIFICATION

I, Kriangsak Siripongsaroj, declare that this thesis, submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy, in the Department of Economics, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

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ABBREVIATIONS

ADF = Augmented Dicky and Fuller Statistic

AGDP = Agricultural Gross Domestic Product

AIC = Akaike Information Criterion

AP = Average Product

Baht = Thai Unit of Currency; during much of the 1980's and 1990's, US$1 = 25 Baht (except after the period of economic in Thailand)

DF = Dicky-Fuller Statistic

GDP = Gross Domestic Product

HYVs = High Yield Varieties

IRRI = International Rice Research Institute

LM = Largrange Multiplier

MC = Marginal Cost

ML = Maximum Likelihood

MVs = Modern Varieties

NESDB = National Economic and Social Development Board (Thailand)

NSO = National Statistical Office (Thailand)

OAE = Office of Agricultural Economics (Thailand)

OLS = Ordinary Least Squares

Rai = Thai Unit of Area; 1 Rai = 40m*40m or 0.16 Ha

R&D = Research and Development

R&E = Research and Extension

ROR = Rate of Return

RRI = Rice Research Institute (Thailand)

SBC = Schwarz Bayesian Criterion

TDRI = Thailand Development Research Institute

TFP = Total Factor Productivity

VAR = Vector Autoregression/Autoregressive

VMP = Value of Marginal Product

ABSTRACT

The contribution of agricultural R&D investment to productivity is recognized as one of the most important indicator for policy making in economic development. Several empirical studies of R&D evaluation have attempted to create an appropriate approach to calculate the rates of return to agricultural R&D investment. Although many approaches are used to evaluate agricultural R&D investment, none is superior in all situations. This study attempts to use a new approach, employing R&D knowledge stock and its depreciation, modern time series data analysis, and OLS method to calculate the rate of return to R&D investment, rather than R&D expenditures with specific lag structures and OLS estimation.

This study applies the problem of rice productivity in Thailand as a case study. Thailand has a very low rice yield per hectare compared to other countries in Asia and throughout the world with similar agro-climate conditions and land endowments. The question is then how successful the continuing high yield has been, and what are its causes and effects. Rice R&D is focused whether it is a major determinant stimulating rice yield growth, and whether its allocation is far below the optimum level. Thus, the purpose of this study is to investigate the causes and effects of rice yield growth and to evaluate the contribution of R&D to rice yield.

The major findings of this study suggested that chemical fertilizer, irrigation, current R&D, R&D knowledge stock, and rice growing land were the main interacting factors determining rice yield in Thailand during 1967 to 1998. Rates of return to R&D investments were calculated with standard formulae by two approaches: the traditional approach and the stock approach with depreciation rates. When time-series data of R&D knowledge stock during 1950 to 1998 was used, the traditional approach of the second-degree polynomial technique can capture the lag structure of 8-years lag, inverted-U-shaped lag. The rate of return to R&D investment was 44.54 percent per annum. The stock approach used R&D knowledge stock as a research variable in the rice yield function and the concept of depreciation of capital stock was used to determine lag length rather than R&D expenditure with a specific time lag structure. Using different depreciation rates of R&D knowledge stock, this

study found that, if there was no depreciation, the rate of return to rice R&D investment was 17.93 percent. However, if depreciation rates of R&D knowledge stock were 5, and 10 percent per annum, the rates of return increased to 25.72 and 36.42 percent respectively. These rates were a high and attractive return for an investment of this nature. These rates of return also showed that rice R&D in Thailand was under-investment.

Finally, the study had estimated the impact of R&D through rice yields on income generation and poverty alleviation and found that rice yields had a positive relationship with farm and non-farm household income and farm and non-farm per capita income, and had a negative relationship with the poverty level. This means that R&D investment by increasing the rice yield could enhance farm and non-farm income and alleviate poverty in Thailand. In conclusion, the very low rice yield in Thailand could be partly explained by insufficient R&D investment in the past. The effort in rice R&D affected to an increase of incomes and a reduction of poverty in Thailand.

This study suggests that policies to enhance rice yield growth in Thailand require urgent attention. Improvement of chemical fertilizer usage, irrigation, R&D, and rice growing land should be combined as they are the major factors required to accelerate rice yield. The existing R&D knowledge stock in rice should be augmented with greater investment in R&D, while rice R&D organisation should be modernised to compensate for the depreciation in R&D knowledge stock. Rice R&D should be used as an important policy instrument, resulting an increase of income and a reduction poverty level in Thailand.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Thailand has been a major rice exporter to a thin world market for rice since 1950. Major technological progress in wheat and rice production during the 1960's and 70's, known as "the green revolution", helped increase rice yields in most countries of Asia. However, Thailand's record in this context has been disappointing. The reasons for this are complex. This study deals with one of them, namely the Thai government's research and development policy affecting rice production and yields.

Investment in agricultural research and development (R&D) is recognized as one of the most important strategies to achieve food security or otherwise improve market share. These activities not only produce and improve knowledge and materials which are used as the new technologies and management practices in agricultural development. R&D also contributes to the successful adaptation of innovations from abroad for local use. New varieties of seed, improved livestock, and farm machinery are all generated from R&D activities. These new and improved technologies contribute to agricultural productivity growth, and reduce the unit cost of production. These technologies stimulate economic growth and structural change. Impact on income distribution depends upon historical factors, as well as policy induced economic growth and its sharing.

Modern technologies for agricultural production generated by agricultural R&D encourage agricultural development in many ways. According to Evenson (1993), many studies show that agricultural R&D affects the use of inputs like chemical fertilizers, seed and feed and farm machinery. Firms contribute to farm productivity, partly through these inputs. According to Antle & McGuckin (1993: 175), the high rates of agricultural growth in the United States in the latter half of the 20th century are a direct result of a science-based system of technological innovation in agriculture. These technologies were created through a system of public and private research and development. On the other hand, Pray and Neumeyer (1990) state that declining R&D will lead to a decrease in US food and agricultural productivity. Such a decrease will cause a decline in farm incomes and US competitiveness in agricultural exports.

Although agricultural R&D plays an important role in economic development, investment in it requires some public funds and must compete with other public activities for scarce resources. This issue is of particular importance for developing countries. With this resource scarcity, governments allocating agricultural R&D funds must be assured that the resources used in a given investment project would not have a better alternative use in the priorities of that country. Therefore, the efficient allocation of scarce public funds to achieve the economic development goal of the developing country is of paramount importance. For this purpose, assessment of the rate of return to R&D investment is essential, if it is to be used as an indicator for the efficient allocation of R&D funds.

Several approaches to measure the contribution of R&D to agricultural productivity listed in Norton and Davis (1981), Echeverria (1990), Harris and Lloyd (1991), and Alston *et al* (1998a) are in use. No one approach is superior in all situations. These studies cover both *ex ante* and *post ante* evaluation of R&D expenditures, the consumer-producer surplus approach, and production function approach. Each of these methods has theoretical or practical limitations. In recent years, a few studies have used modern time-series econometric approach to tackle some of these problems. However, a time series of a short period of annual observation of R&D (extension) expenditures is not sufficient to estimate the R&D lag profile relationship accurately. The controversy over lag length, smoothness and shape are important issues that need to be confronted. This study deals with the issue of rice productivity in Thailand and examines the role of R&D in Thai rice sub-sector.

1.2 Agriculture, Economic Growth of Thailand and Problems

Over the period of 1961-1997, Thailand had experienced an impressive economic growth record. The average annual growth rate of real GDP was 7.9 percent in the 1960's, almost 7 percent in the 1970's, then falling to 5.4 percent in the 1980's, and rose up again to 7 percent again during 1991-1997 (Table 1.1). The large expansion of agricultural production and rapid industrialization are considered by some as the reason for such rapid growth. However, there is evidence clearly showing that the Thai economy has transformed from agricultural-based to industrial-based since the 1960's. The structural change from an agricultural to industrial economy is shown in Table 1.1

Table 1.1 also shows that the relative contribution of agriculture to GDP has declined. The agricultural sector was a leading sector of the Thai economy in the 1960's and the 1970's accounting for approximately 40 and 28 percent of GDP respectively. However, since the 1980's, the industrial sector has become increasingly more important. Although the share of agricultural sector in GDP in the

1980's dropped slightly to 25.4 percent and sharply decreased to 11.54 percent during 1991-1997, the growth rate of the agricultural sector was still remarkable for nearly four decades. The real growth rate of agricultural sector grew by 5.5 percent, 4.3 percent, and 4.7 percent in the 1960's, 1970's, and the 1980's respectively, then dropped drastically to 2.7 percent during 1991-1997.

In the same period, the share of the manufacturing sector in GDP started at 18.2 percent in the 1960's, and increased significantly to 25.3 percent in the 1970's, 28.4 percent in the 1980's and 30.59 percent during 1991-1997. The real growth rate in this sector was high and fluctuated between 4.4 and 10.9 percent per annum. The average growth rate was 10.9 percent in the 1960's, and slightly decreased to 9.3 percent in the 1970's. In the 1980's, the growth rate was not typical for this sector, rapidly dropping to 4.4 percent, because of the second oil shock during 1979-1980 (Krongkaew, 1995). However, from 1990-1997, the average growth rate of the manufacturing sector was continuously high at 8.9 percent.

Table 1.1: Share of GDP by Sector and Growth Rate

Economic Sector	1961-70	1971-80	1981-90	1991-97
GDP (%share)				
Agriculture	39.8	28.3	25.4	11.54
	(100.00)	(100.00)	(100.00)	(100.00)
Rice	(33.53)	(29.05)	(22.99)	(17.57)
Manufacturing	18.2	25.3	28.4	30.59
GDP (% growth)				
Agriculture	5.5	4.3	4.7	2.7
Manufacturing	10.9	9.3	4.4	8.9

Source: Krongkaew (1995) and NESDB (data between 1991 and 1997)

Although the agricultural sector contributed only 11.54 percent of GDP between 1991 and 1997, agriculture still continues to increase in value. Approximately 60 percent of the Thai people still continue to rely on agriculture. As such, any change in agricultural policies will directly affect the majority of Thai people, indicating the continued importance of the Thai agricultural sector and the need for continual development.

Although Thailand's economy has undergone remarkable expansion, and agricultural structural change, many problems have arisen. Numerous studies have reported that the overall economic development of Thailand was successful due to natural resources utilization. Previous growth of the agricultural sector was mainly due to the conversion of forest area to cultivated crop area (Siamwalla *et al*, 1993). In addition, the inefficient use and deterioration of natural resources has increased, with the potential to generate problems within the agricultural production system. As such, these problems may gradually force Thai agriculture forward to capital-intensive and research-intensive production.

Although Thai agriculture is slowly becoming more capital and research intensive, evidence shows that improvements in yields of individuals crops such as rice, maize, rubber, oil crops and fiber crops are small and still low compared with many other countries in Asia. This may be due to the slow uptake of improved agricultural technologies and inputs which have been generated from agricultural R&D. Indeed, Thailand may be one of the countries seriously under-investing in agricultural R&D. Efforts to improve and sustain agricultural productivity require technical change which is generated by R&D.

While the agricultural sector is becoming less important within the Thai economy in terms of GDP share, the crop sub-sector remains the most important, accounting for more than one half of the total value of the agricultural sector output since 1960. Among the major crop groups, rice has been the most important agricultural commodity and a major export revenue earner. Although the importance of rice in relative terms has declined over the past four decades, from 33.53 percent during 1961-1970 to 17.57 percent during 1991-1997, rice continues to be an important crop. It accounts for about one-fifth to one-third of total agricultural GDP since 1960 (Table 1.1). According to Isvilanonda and Poapongsakorn (1995: 2), Thailand is a major rice supplier in the world market because Thai rice is of high quality. Thailand also enjoys a relatively high comparative advantage in production cost, resulting from area expansion and previous applications of R&D.

However, the importance of rice to the Thai economy has declined significantly since middle of the 1960's. This is due to an import diversification policy in which other crops such as fruits and vegetable have been promoted to increase their roles in the economy (TDRI, 1988; Siamwalla *et al*, 1993). Consequently, the ratio of rice area to crop area gradually decreased from a 74.57 percent yearly average during 1961-1970 to 56.16 percent during 1991-1998. The share of rice output in agricultural R&D also dropped from an average of 33.85 percent an average during 1961-1970 to 20.77 percent during 1991-1998. However, rice still remains the most important crop for Thailand, accounting for 56.16 percent of total crop area during 1991-1998, no other crop takes its place (Table 1.2).

Table 1.2 Ratios of Rice and Crop in Cultivated Area and AGDP in Thailand, 1961-1998 (Percent)

Period	Rice /Crop Area	Rice Value/AGDP
1961-1970	74.57	33.85
1971-1980	63.14	29.21
1981-1990	56.16	24.38
1991-1998	56.16	20.77

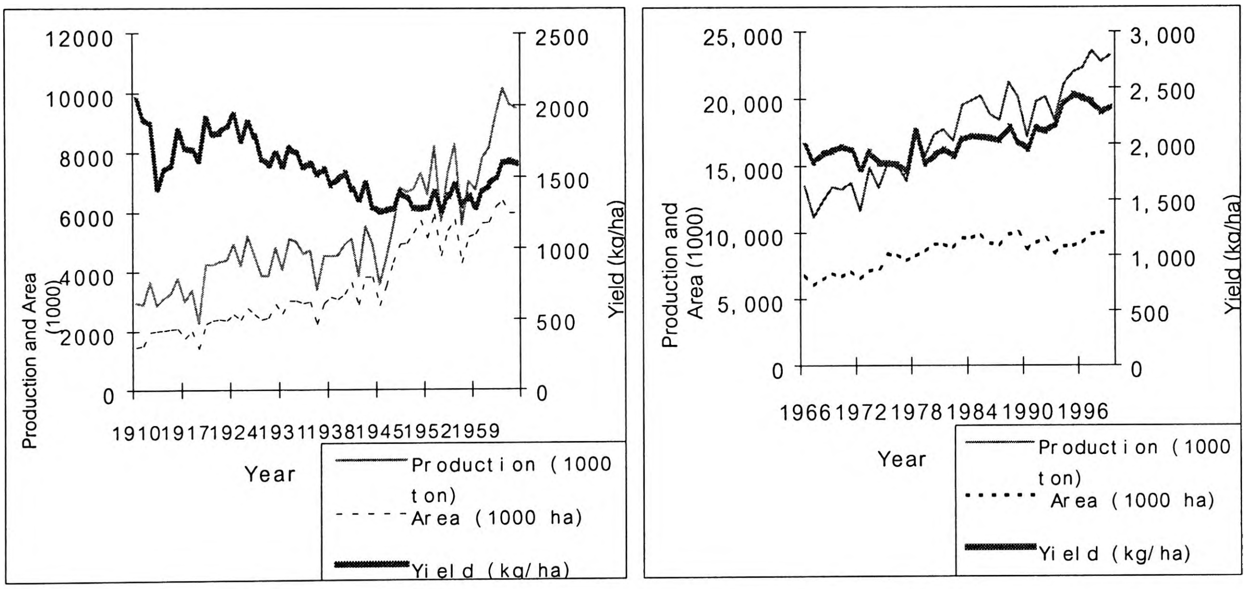
Source: Computed from data in Table A.4 (Appendix A)

Thailand is a large rice-producing country, accounting for approximately 4-5 percent of total world production. Over the past decade about 10 million hectares of rice has been planted each year, and paddy production has fluctuated around a mean of 20 million tons. Nearly one-fourth of this area is irrigated and the rest is rainfed. Approximately 25 percent of total production has been exported.

Thailand has been one of the world's leading rice-exporters since the early 1960's because Thai rice has a reputation for being of high quality, long and white grain (Faber and *et al*, 1978, and IRRI, 1993). Thailand took over the leading position from the USA in the 1980's, and held this position for some time. However, recent figures show Thailand's world market shares of rice exports have been declining since the 1990's. Conversely, the export share of Vietnam, India and China has increased sharply during the same period.

Furthermore, the average rice yield in Thailand had been on a serious downward trend since 1910 up, until the middle of 1950's. The trend then started to reverse, and since 1958 it had been on the increase (Figure 1.1a). Since then and until recent years, the fluctuation of the low growth rate has been rising (Figure 1.1b). The average growth rate of rice yield in Thailand during 1961-1999 was only 0.73 percent per annum. This growth rate is very low in comparison with the 2.02 percent world growth rate during the same period. Moreover, the gap between average rice yield of Thailand and that of the world and Asia has been widening over time (Figure 1.2).

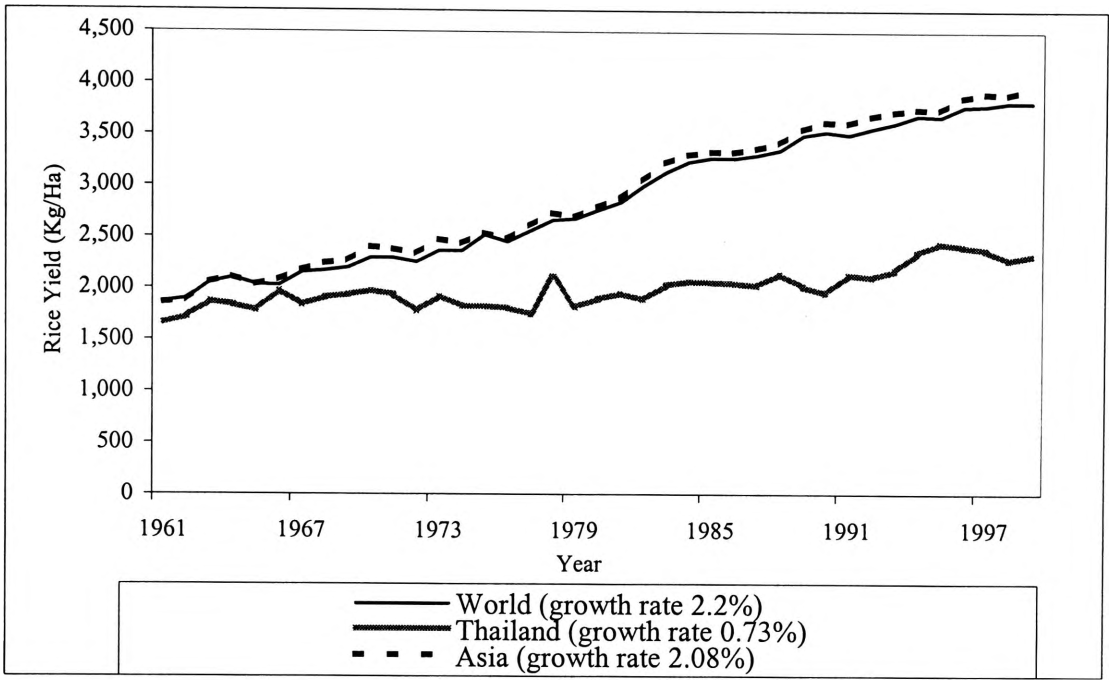
Figure 1.1 Trends of Rice Area, Production, and Yield in Thailand, 1910-1965 and 1966-1999



(a) (b)

Sources: Isrankura (1966) and Table A.1 (Appendix A)

Figure 1.2 World's, Asia's and Thailand's Rice Yield, 1961-1999



Source: Table A.1 and A.2 (Appendix A)

The inability of the Thai rice industry to keep up with global and Asian trends impacts the domestic rice production system and rice economy of Thailand in several ways. Firstly, the substantial downward trend of the world's real rice prices is still continuing, despite the decline of the world's rice production growth in recent years (Pingali *et al*, 1997). As Thailand continues to produce rice with very low yield, the unit cost of rice production increases. If the world's rice prices continue to decline (Figure 1.3), unit cost of production will increase and farmers' profits from rice cultivation will decline (Table 1.2). Marginal farmers will shift to other crops which provide better profits than rice. Thailand's rice exports will suffer if this trend continues. Thailand will lose its leading position and comparative advantage in the world's rice market.

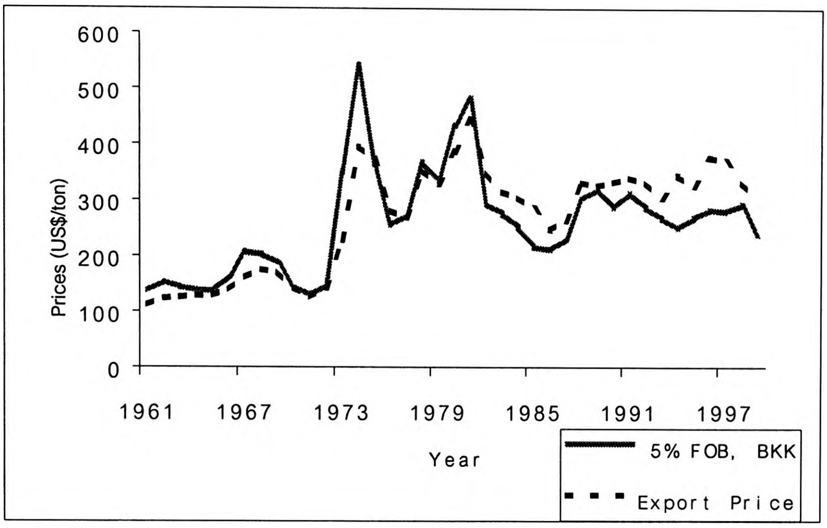
Table 1.3 Average Farm Price, Cost and Profit from Rice Farming in Thailand

Year	Farm Price (Baht/ton)	Production Cost (Baht/ton)		Profit (Baht/ton)	
		Second Rice	Major Rice	Second Rice	Major Rice
1984-86	3846	2502.30	2964.60	1343.70	881.40
1988-90	3739	2793.0	3158.09	946.00	580.91
1991-92	3547	2570.37	3197.39	976.63	349.61
1993-94	3792	2747.20	3588.04	1044.80	203.96

Source: OAE

Secondly, the rice economy generates both farm and non-farm income through rice production, sales, trading, processing, and agricultural inputs used in rice growing. Loss of world market share in rice will not only affect the agricultural sector but the entire economy. This is because rice is a staple food and a major revenue-earning crop of Thailand. The rural and non-rural economy of Thailand depends considerably on the economy of rice. Rural poverty is related to farmers' income, and rising their income will alleviate poverty.

Figure 1.3 Trends of World's Rice Prices, 1961-1999



Source: Table A.5 (Appendix A)

In summation, the declining of rice production of Thailand's share in the world, the continually widening gap between Thailand's yield and the world's, and the remaining high cost of production for Thailand are the signals determining the change in rice trade and the whole economy of Thailand. If Thailand refuses to direct more attention and investment towards rice development, particularly the improvement of rice yields, it is a danger of losing its position as leading rice-exporter in the market therby increasing the level of poverty. Although Thailand has attempted to develop the rice industry through R&D activities since the early 1950's, rice yield performance continues to be unimpressive. Rice yields in Thailand remain very low compared to other countries in the world (except Cambodia), which have similar agro-climate conditions and land endowments[1]. In 1999, the rice yield in Thailand was only 2,327 kg/ha, while the average rice production in Asia was 3,903

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[1] Data from FAO (://www.fao.org).

kg/ha, in India 2,929 kg/ha, Indonesia 4,261 kg/ha, Vietnam 4,105 kg/ha, Myanmar 3,128 kg/ha, Philippines 2,863 kg/ha, and China 6,321 kg/ha.

The large investment in irrigation infrastructure and the pervasive use of chemical fertilizer in order to response MVs, the main causes of striking rice yield in the 1960's. Besides, changes in cultivation techniques together with the effort in R&D during the same period were the important factors to stimulate rice yield growth (Fukui, 1978: 258; Isvilanonda and Poapongsakorn, 1995:14 and 38). It is worth noting that this striking increase in Thai rice productivity corresponded with the period of hard effort in rice R&D since the early 1950's[2]. Thus, it is very tempting to investigate whether such a continuous increase is attributed to the past R&D effort in rice, and if the current allocation of R&D funds for rice in Thailand is appropriate.

Moreover, the percentage of agricultural gross domestic product (AGDP) spent on agricultural R&D of Thailand in 1970, 1975, and 1983 were 0.73 percent, 0.32 percent, and 0.41 percent respectively. Whereas the percentage of total value of rice spent on R&D expenditure for rice in the same periods were 0.55 percent, 0.14 percent, and 0.23 percent respectively. According to the World Bank (1981), the appropriate percentage for investment in R&D compared with AGDP in developing countries should range from 1 to 2 per cent. This statistic clearly shows that Thailand is facing the problem of under-investment in agricultural R&D and specially R&D

[2] Rice Department in Thailand was established in 1954.

for rice. This situation may lead to a high rate of return for R&D investment in rice.[3] Furthermore, the impact of rice R&D and poverty alleviation attributed to the increase of rice yield are important to form the appropriate policy for development.

Although there were some studies evaluating the agricultural R&D performance in Thailand (ESCAP, 1977; Isarangkura, 1981; Adulavidhaya *et al*,1986; Pochanukul, 1986; Setboonsarng and Khaoparisuthi, 1990; Setboonsarng *et al* 1990; Setboonsarng and Evenson (1991); Pochanukul, 1992), none of them had studied the relationship between agricultural productivity and R&D expenditure by using the cointegration and causality approach. The most important point is that no previous works have applied the R&D stock of knowledge and cointegration approach to measure the source of rice yield growth and calculate the rate of return to R&D investment in rice crop. Therefore, providing such information is crucial to set the appropriate policy for Thailand, particularly for allocating resources to stimulate rice productivity. In order to test the hypotheses whether rice R&D investment is an important factor in determining rice yield growth, the relationship between rice yield growth and relevant inputs is examined. Moreover, investment in rice R&D should be investigated as to whether it is feasible for the nature of such investment to stimulate rice yield growth. Finally, the effect of rice yield increase to alleviate poverty in Thailand should be undertaken.

[3] According to Pinstrup-Anderson (1982: 101), Fox (1985), Barker *et al* (1985: 203), Thirtle and Bottomley (1988), and Evenson *et al.* (1999), the high rate of R&D return is an indicator that public investment in agricultural R&D has been far below the optimal level

1.3 Objective

In general terms, this study is designed to investigate the cause and effect of rice yield growth, and to evaluate the contribution of rice R&D to rice yield in Thailand for the period 1967-1998. The specific objectives are to:

(a) investigate the relationship of rice yield and determining inputs;

(b) evaluate the rate of return to R&D investment in rice;

(c) examine the impact of rice yield change on income and poverty level;

(d) formulate the public policy implications regarding how to accelerate rice productivity growth for Thailand.

1.4 Research Approach

To achieve the objectives of this study, firstly, a selection of previous works especially those dealing with the contribution of agricultural R&D to production and productivity was conducted. An appropriate approach was selected to examine the relationships between rice productivity and expected explanatory variables. An empirical framework, methodology, models, and data sources are presented, and econometric analysis methods were used to test the relationships based on available time-series data.

The first step is to describe and analyse the picture of the production economy of Thai rice and agricultural R&D system. The relationship between them is described and reviewed in order to preliminarily determine the determinant input of rice productivity, especially the three major determining inputs: fertilizer, irrigation, and R&D. The overview of rice development and the agricultural R&D system in

Thailand are presented as a background to this study. Furthermore, the effects of rice yield growth to increasing income and poverty alleviation are investigated.

The second step is to use the approach, which is distinctive from the conventional production function approach, relying on R&D expenditures with the specific time lag profile and OLS procedure. In this study, the cointegration with Johansen procedure, which is the contemporary approach, is used to estimate the sources of rice yield growth and calculate the contribution of rice R&D investment to rice yield in Thailand during 1967-1998.

With this approach, firstly, econometric models of rice productivity are presented. Expected inputs involved and R&D variables are used as the factors determining rice yield in Thailand. Secondly, all relevant time-series data are tested as to whether they are stationary. Augmented Dicky-Fuller test (Dicky and Fuller, 1979; Dicky, 1981) is used. In general practice, if a set of time series data used in the models is characterized as a non-stationary, regression estimated with OLS method will yield artificial and misleading results when one non-stationary time series is regressed on another one. In order to avoid the problem of spurious regression when time series data are non-stationary, the different data is applied. However, the estimated regressions in differences may lose any valuable long-term information of the relationships between variables; then it is important to consider regression models in level rather than their differences. Thirdly, if the time-series have the same properties, the cointegration method is used to test whether relevant time-series are cointegrated in the system. With the Johansen procedure or the maximum likelihood cointegration technique (Johansen, 1988; Johansen and Juselius, 1990) is applied to detect the existence of the long-run relationships among the same property time series data in the models. With this procedure, cointegrating regressions are estimated by using the Microfit4 package. After normalization on the dependent variable so that it appears with a coefficient of 1, is given a single cointegrating relationship or a preferred cointegrating vector. Then t-statistics is applied to test whether the coefficients in the preferred vector are statistically significant by testing restrictions on the elements of the cointegrating vector. Finally, causality is applied to confirm the cointegration test results and to test the direction of the relationships.

In the final step, after appropriate regressions are selected, obtaining appropriate coefficients of each determining input, the sources of rice yield growth are determined and the shares of inputs are estimated based on the coefficients from the preferred vectors and rice yield and inputs growth rates. The rates of return on R&D investment are also calculated, based on these coefficients and lag length. Finally, before the public policy implication regarding enhancing rice productivity in Thailand is drawn, the impacts of agricultural R&D investment, through rice yield growth, on income generation and poverty alleviation are examined. This is believed since policy makers would be concerned over the impact of such investment on economic development.

1.5 Organisation of the Thesis

The remaining seven chapters of this study are organized as follows. Chapter 2 is to devote to an overview of the world rice situation; dealing with aspects of production, trade and rice R&D from a Thai perspective. The purpose of this Chapter is to present the picture of world rice economy, trade and R&D investment and compare it with Thai rice.

The background and characteristic of the Thai rice production economy, agricultural R&D system, and the causes and effects of rice yield trends are discussed in Chapter 3. This chapter starts with a brief overview of the production economy of Thai rice, which covers the trends of rice production, cultivated area, yield per hectare, yield variation, and input uses. Thai agricultural R&D system, including a historical background of R&D on crops, agricultural R&D organization and R&D expenditure are presented in the second part of the chapter. The third part of the chapter deals with the relationships of rice yield and its determinants. Finally, the effects of rice yield on household and per capita income of both non-farm and farm incomes are investigated.

Chapter 4 is divided into two parts: a theoretical framework and literature review. The first part presents the theoretical and conceptual framework of the economic issues of evaluation and priority settings in agricultural R&D. The chapter starts with the basic concept of productivity and agricultural R&D, including the definition and system of agricultural R&D and technology. Time lag profile is also presented as an important issue for calculating the rate of return to R&D investment. The second part deals with the main strands of literature on the subject of agricultural R&D and assessment of economic returns to R&D. Due to enormous literature on agricultural R&D and its returns, this part attempts to restrict the scope of surveys dealing with three main approaches: economic surplus approach, cost-benefit analysis approach and econometric approach which is classified into production function approach, TFP with production function approach, dual approach, and cointegration approach. The chapter ends with a conclusion and evaluation of the previous major contributions.

In Chapter 5, Firstly, the empirical models are designed in order to describe the relationships between rice yield and explanatory variables for Thailand rice sub-sector. Secondly, the unit root test is employed to test whether relevant time-series variables are stationary. Thirdly, cointegration technique with the Johansen procedure is applied to investigate whether the time-series data in the system have a long-run stable relationship. Fourthly, the model is estimated and the coefficients of the feasible regressions are selected and tested as the major determinants in the system. Finally, causality analysis is confirmed to test the direction of the causal relationships. The period covered for the empirical analysis is 1967 to 1998.

In Chapter 6, from the results of OLS method, the best-fit regression is used to determine and to calculate the rates of return to R&D investment with both traditional and stock approach in the first section. Finally, in the second section, the relationships between rice yield and poverty levels are examined as the implication of rice yield for poverty alleviation.

Chapter 7 draws conclusions from the findings of the study after presenting a summary of main points from previous chapters. The implication for public agricultural R&D policy in Thailand is discussed and policy implications and recommended suggestions for future study are presented.

CHAPTER 2

WORLD RICE ECONOMY: THAI PERSPECTIVE ON PRODUCTION, TRADE AND R&D

2.1 Introduction

Thailand has been a major rice-growing and rice-exporting country since 1855 when the Bowring Treaty with U.K. opened up the country to international trade on a significant scale (Corden and Richter, 1967: 128). Thailand contributes around 4-5 percent of the world's rice production. About 20-30 percent of the total rice production of Thailand is exported. The rice-export share of Thailand in the world market has fluctuated widely within a range of 10-35 percent since the 1960's. Thailand emerged as a leading rice-exporter after the Second World War.

However, in recent years, the rice production environment and trade situations of the world have been changing. As a major rice-growing and rice-trading country, Thailand may have some direct impacts from these situations, both in domestic and international aspects. The changes are examined in an international view with Thai perspective in this chapter. The focus of this chapter is to present an overview of the current situation of world rice economy from Thailand's perspective. World rice production, trade and R&D investment and Thailand's position in the global rice economy are examined to study trends of rice harvested area, production, yield, international trade including the relationship between rice productivity, inputs use and R&D expenditures.

This chapter is divided into three sections. Section one deals with the world production of rice and Thailand's share in it. Section two examines the worldwide trade of rice and the changing share of Thailand. The third section deals with a cross-country comparison detailing the relationship between rice yields and the intensity of adoption of HYVs, irrigation ratios, fertilizer use, and R&D expenditures in selected countries. Finally, the trends in R&D expenditure in rice production systems are presented in the last section.

2.2 Rice Production Perspectives of the World and Thailand

About two billion eight hundred of world population are dependent on rice. Nine-tenths of the rice area is grown in Asia and distributed around the world. In the second half of the twentieth century the world rice production averaged between 160-200 million metric tons for an average of around 100 million hectares. The average rice yield for the world as a whole was about 1.6 metric tons per hectare. The major rice-growing countries are China, India, Japan, Pakistan, Indonesia, Thailand, and Myanmar (Roche, 1992). Over four decades (1961-1999), following the spread of modern rice varieties in the 1960's, known as the green revolution, rice production of the world has almost tripled from 215 million metric tons in 1961 to 596 million metric tons in 1999, with average rice yield of 2,854 kg/ha (Table A.1 in Appendix A).

A comparison of sources of rice production growth show in the first twenty-year period (1961-1980) about 63 percent of the growth came from an increase in rice yield and about 37 percent from area expansion. In the latter period (1981-1999) almost 80 percent of the production growth come from yield increases and only about

20 percent from area expansion. However, over the four decades (1961-1999) The world's rice production increased by an annual growth rate of 2.62 percent per annum. About 77 percent of the total production increase came from yield increases brought on by technological progress gained through research (Hossain and Pingali, 1998:4). Moreover, in the same period, the world's rice yield grew by 2.02 percent per annum, mainly through the replacement of traditional rice varieties with more modern strains (Pingali *et al,* 1997).

Although the world's rice production, harvested area and yield had been all increasing, the tendency of growth rates have been decelerated in recent years. The growth rate of harvested area of rice dropped sharply from 1.11 percent per annum in 1961-1980 to 0.36 percent per annum in 1981-1999, together with the declining growth rate of yield from 1.88 percent in 1961-1980 to 1.46 percent in 1981-1999. Together, the two diminishing rates resulted in a decline in the growth rate of production from 2.99 percent in 1961-1980 to 1.82 percent in 1980-1999 (Table 2.1).

Thailand's share of global rice production and yield has been decreasing since the 1980's. Although the rice area, production, and yield of Thailand and indeed the world had increased over almost four decades, the share of Thai rice in the world production, harvested area and yield have not kept pace. While Thailand's share of harvested areas increased from 5.41 percent to 6.39 percent in 1961-1980 and 1981-1999, the share of rice yield decreased from 81.36 percent to 62.21 percent. The share of world rice production for Thailand dropped from 4.39 percent per annum in 1961-1980 to 3.96 percent per annum in 1981-1999 (Table 2.1).

Table 2.1 Average Rice Production, Area, Yield and Growth Rate in the World and Thailand, 1961-1999

		World			Thailand	
Period	Production (1000 tons)	Harvested Area (1000 ha)	Yield (kg/ha)	Production (1000 tons)	Harvested Area (1000 ha)	Yield (kg/ha)
1961-1999	404,954 (100.00)	139,767 (100.00)	2,854 (100.00)	16,733 (4.13)*	8,263 (5.91)*	2,000 (70.07)*
1961-1980	305,573 (100.00)	132,754 (100.00)	2,285 (100.00)	13,438 (4.39)*	7,185 (5.41)*	1,859 (81.36)*
1981-1999	509,565 (100.00)	147,149 (100.00)	3,454 (100.00)	20,202 (3.96)*	9,397 (6.39)*	2,149 (62.21)*
Annual Growth Rate (percent)						
1961-1999	2.62 (100.00)	0.60 (22.90)	2.02 (77.10)	2.05 (100.00)	1.32 (64.39)	0.73 (35.61)
1961-1980	2.99 (100.00)	1.11 (37.12)	1.88 (62.88)	2.25 (100.00)	1.93 (85.78)	0.32 (14.22)
1981-1999	1.82 (100.00)	0.36 (19.78)	1.46 (80.22)	1.33 (100.00)	0.16 (12.03)	1.17 (87.97)

Sources: Computed from data in Table A.1 (Appendix A)

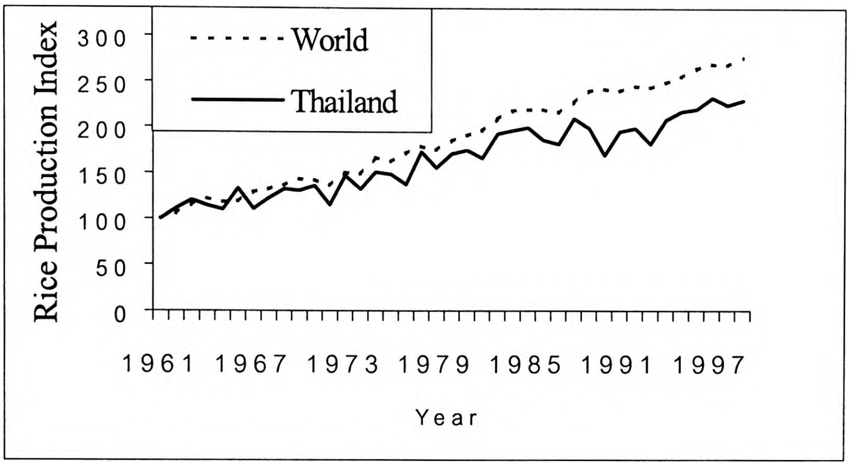
Notes: 1) The figures in brackets are the percentage.

2) The growth rates are computed by fitting semi-logarithmic trend lines to time-series data (semi-log method)

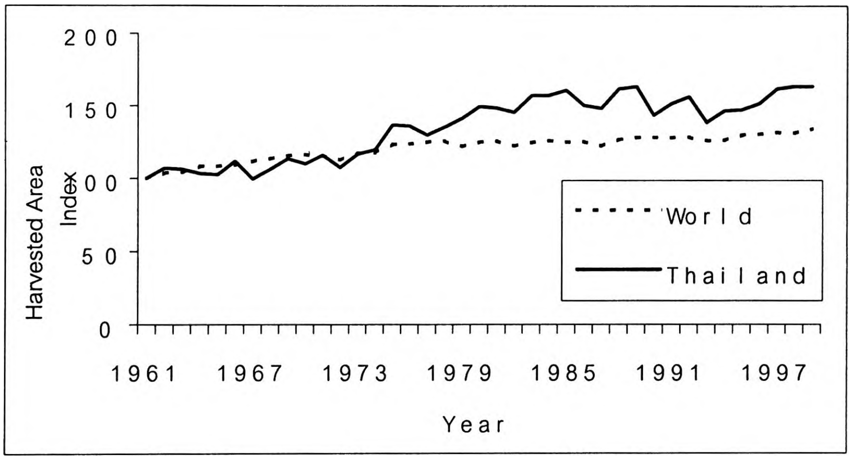
3) All computed growth rates are statically significant at 5 percent.

4) * is the percentage share compared to the world

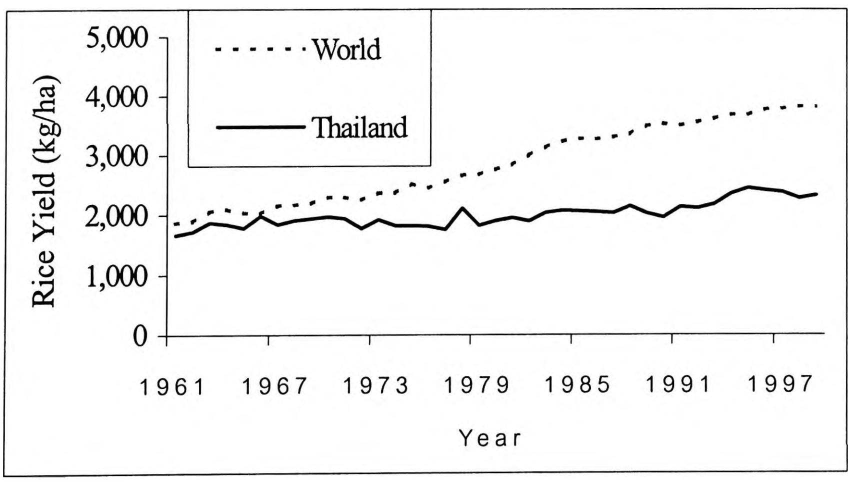
Figure 2.1 Rice Production, Area, and Yield of the World and Thailand



(a)



(b)



(c)

Source: Data from Table A.1 (Appendix A)

Although the growth rate of rice yield in Thailand increased from 0.32 percent per annum in 1961-1980 to 1.17 percent per annum in 1981-1999, the growth rate of harvested area dropped sharply from 1.93 percent per annum in 1961-1980 to 0.16 percent per annum in 1981-1999. This led to a decline in growth rate of rice production from 2.25 percent per annum in 1961-1980 to 1.33 percent per annum in 1981-1999.

Although Thailand rice yield has been increasing, the average growth rate of Thailand's rice yield was still lower than the average growth rate of the world's rice yield during 1961-1999. Thailand's rice yield increased only 0.73 percent per annum, while the world's rice yield grew up by 2.02 percent per annum (Table2.1). It is clear that the index of rice production of Thailand has increased less than the index of the world production since around the middle of the 1970's. Moreover, the gap between the world's rice yield and Thailand's rice yield has been widening over time (Figure 2.1(c)). This situation will affect Thailand's comparative advantage and production cost per unit when compared to the other countries.

Table 2.2 shows a comparison of the growth of rice production and yield for seven major rice-exporting countries during 1961-1999. The growth of rice production in Thailand during 1961-1999 was the lowest of all selected countries. Moreover, Thailand's production growth between the period 1961-1980 and 1981-1999 decreased from 2.25 percent per annum to 1.33 percent. This decline also occurred in the USA, Myanmar, Pakistan, and China. During the same period however, the rice-production growth of Vietnam and India increased sharply as a result of increase in their rice yields. Although the rice yield in Thailand increased from 0.32 percent per annum during 1961-80 to 1.17 percent during 1981-1999, this increasing growth was still much lower than that of Vietnam and India.

Table 2.2 Growth Rate of Rice Production and Yield of Major Rice-Exporting Countries, 1961-1999

Country	Growth in Rice Production			Growth in Rice Yield		
	1961-99	1961-80	1981-99	1961-99	1961-80	1981-99
Thailand	2.05	2.25	1.33	0.73	0.32	1.17
United State	2.86	4.09	2.08	1.18	0.96	1.19
Vietnam	3.36	1.25	4.87	2.15	0.41	3.07
Myanmar	2.78	2.22	1.75	2.34	1.99	0.14*
Pakistan	3.34	6.26	2.05	1.63	3.59	0.87
China	2.81	4.30	1.20	2.70	2.78	1.66
India	2.75	2.27	3.01	2.13	1.51	2.40

Sources: Computed from data in Table A.2 (Appendix A)

Notes: 1) The growth rates are computed by semi-log method.

2) All computed growth rates are statically significant at 1 percent.

3) * is not significant at 5 percent

Finally, the production cost per ton of Thai rice is higher than that of many major rice-growing countries. Table 2.3 shows the production cost per hectare of land and per ton of output in selected countries. The cost of rice production per hectare in Thailand was lower than many other countries. However, the cost of production of rice in Thailand per ton of output was higher than that of many other selected countries. Thailand is gradually losing its comparative advantage in rice production due to the relatively high costs per unit output resulting from the low rice yield when compared to many major-rice-growing countries and current major-rice-exporter countries such as Vietnam and China. This affects farmers incomes and rural poverty.

In summary, the low rice yield of Thailand and the widening gap between Thailand's yield and the world's and consequent high cost of production in Thailand are the signals determining the changes in the rice trade of Thailand in the world markets. Thailand may lose its as the position of leading rice-exporter in the world market if low rice yields are not addressed.

Table 2.3 Rice Yield and Unit Costs of Production, Selected Countries, Average 1987-1990

Country	Season/Type	Rice Yield (mt/ha)	Cost of Production (US$)	
			Per Hectare	Per Mt
Bangladesh	Wet Season	3.37	327	97
	Dry Season	4.56	513	113
Vietnam	Autumn	3.80	353	93
	Spring	5.35	333	62
China	Early Season, Indica	5.34	416	78
	Middle Season, Indica	6.49	399	62
	Japonica	6.58	513	78
Indonesia	Irrigated	5.76	474	82
	Rainfed	3.57	389	109
USA	Long Grain	5.94	1,339	225
	Medium Grain	8.57	1,889	220
Thailand	Irrigated	3.78	369	98
	Rainfed	1.84	223	121

Source: Pingali *et al* (1997), Table 6.4

2.3 International Rice Trade

2.3.1 Rice Trade Perspective and the Export Share

The political and economic importance concerning the international trade of rice is sharpened because of the enormous income earning and employment implications in many countries, including Thailand. According to Barker *et al* (1985) and Roche (1992) the growth in the rice trade started in the 1860's as European demand for rice was a critical factor at that time. However, rice trade was also increasing because of a rising demand among Asian countries resulting from World War I. The development of the world rice trade can be divided into two phases. The first period was from 1860's to World War II. The rice export market center was in three delta areas of mainland Southeast Asia: the Irrawaddy in Myanmar, the Chao Phraya in Thailand, and the Mekong in Vietnam. In this period, the countries in the areas tried to open new land to increase surplus production for export. Prior to World War II, three Asian countries: Myanmar, Thailand and Indochina dominated the world rice trade. Myanmar was the largest, shipping 3.1 metric tons in 1940/41, while Thailand came in third, shipping less than half that level. In the the second period starting from the end of the World War II to the 1970's, rice producing countries in Asia continued to dominate world rice trade. During the 1960's and 1970's, major changes have seen the United States, the Middle East and Africa become major rice importers. Vietnam and Myanmar lost their position as major exporters due to internal political problems, and China and Japan shifted their position from importers to exporters.

Table 2.4 shows the major rice-exporters of the world market. Since the 1960's, Thailand, Myanmar, China and the U.S.A. were considered the major rice-exporters in the world market of rice. In the 1960's the USA was the largest exporter with a world share of 18.94 percent, followed by Thailand, China and Myanmar respectively. The U.S.A. was still in the first rank in the 1970's, while Thailand still held the second spot followed by China, Pakistan, and Myanmar. Since the 1970's political unrest has weakened Myanmar's position and it has failed to regain its leading position in the world rice market (Kanivichaporn, 1979). Thailand took over the leading position of rice-exporters from the U.S.A. in the 1980's with a share of 34.21 percent. Since then, Thailand had been holding this position with a share of 29.48 and 25.37 percent in 1991-1995 and 1996-1999 respectively. However, the percent share of export rice in the world market in Figure 2.2 shows clearly that the rice-export shares of Thailand and the USA have been declining since the 1990's, while the export share of Vietnam, India and China has increased sharply over the same period. Myanmar has completely lost its position in the top five-leading exporters around 1988, while Pakistan has held a constant share of the world market since the 1970's.

Although Thailand has a reputation for high-quality, long grain, white, and aromatic rice because of the emphasis of R&D in the past on grain quality (IRRI, 1993), the above evidences show that Thailand may lose her leading position as high-quality rice-exporter to India and Vietnam in the future. In recent years, India and Vietnam have acquired a reputation as high-quality rice producers. Basmati (aromatic) rice from India is highly reputed and exported. Rice consumers generally prefer parboiled long-grain rice with medium to high amylase and strong aroma like

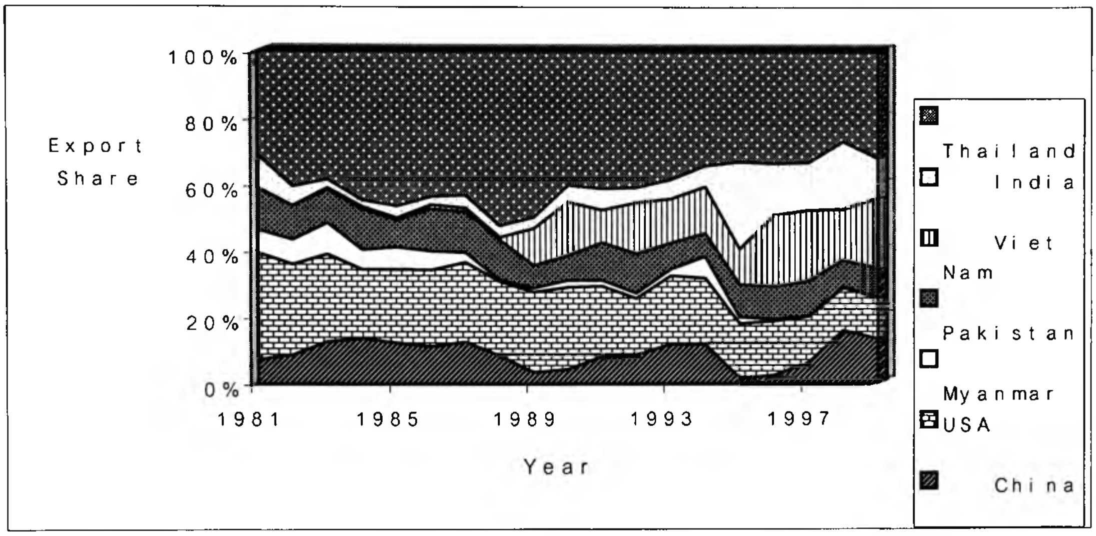
Basmati (Pingali *et al*, 1997:130). At the same time, Vietnam has also exported higher-quality rice, displacing Thailand and has attempted to develop high-quality rice in the country. In recent years, there have been reports of several Japanese rice experts being sent to Vietnam to upgrade their rice quality (Roche, 1992:110). Moreover, the high-quality rice varieties known as Jasmine (IR841) and Khao Dowk Mali 105, which are popular high-quality rice varieties of Thailand are being introduced into many localities in the Mekong River Delta of Vietnam (Khiem, 1998:354).

Table 2.4 Average Percent Share of Rice Exports by Country, 1961-1999

Exporting Country	Percent Share of Exports				
	1961-70	1971-80	1981-90	1991-95	1996-99
Thailand	18.27	19.51	34.21	29.48	25.37
United States	18.94	22.01	19.49	15.00	11.14
Vietnam	-	-	2.82	10.01	15.99
Myanmar	14.12	5.09	3.75	2.23	-
Pakistan	3.48	7.19	8.23	7.60	7.40
China	16.56	18.11	7.05	6.03	8.29
India	-	-	3.27	9.04	12.93
Others	29.63	29.09	21.18	20.61	28.88
Total	100.00	100.00	100.00	100.00	100.00
Average Quantity Trade (1000 tons)	7,773	9,559	12,725	17,319	24,045
Trade Quantity as % of Total Production	2.96	2.74	2.71	3.26	4.14

Source: Computed from data in Table A.3 (Appendix A)

Figure 2.2 Shares of Rice Export of Six Leading Exporters, 1981-1999



Source: Table A.3 (Appendix A)

2.3.2 World Price Trends and Instability

World rice prices have fluctuated over time. Theoretically, demand and supply of rice are considered to be the causes of such instability. However, since rice is a basic-necessity food, its demand is inelastic. Therefore the fluctuating prices depended mainly on supply rather than demand. On the supply side, the weather is a major cause of fluctuation in the world's supply in the short term, whereas technological change appears to have contributed to variability in rice supply in the long term. Moreover, government policies of the major rice-producers and rice-exporters have also influenced the world's price of rice (Barker *et al*, 1985: 191).

In the world market, real rice prices have not only fluctuated over time but also display a decreasing trend. Figure 2.3 shows that real rice price fell substantially from the mid-1970's to 1999, while rice production grew steadily. The downward trend in the world rice price is due to the high competition in a stagnant import market, as the major rice-consuming countries of Asia have become self-sufficient in rice production and have maintained domestic price stability (Pingali *et al*, 1997). The share of Asia in total rice imports was 69.56 percent during 1961-1970. It came down to 58.39, 43.67, and 42.90 percent during 1971-1980, 1981-1990, and 1990-1995 respectively. This decline is particularly noticeable in East and South-East Asia, which are the major rice-growing and rice-exporting countries. The shares of rice imports decreased drastically from 32.33 percent during 1971-1980 to 12.09 percent during 1991-1995 (Table 2.5).

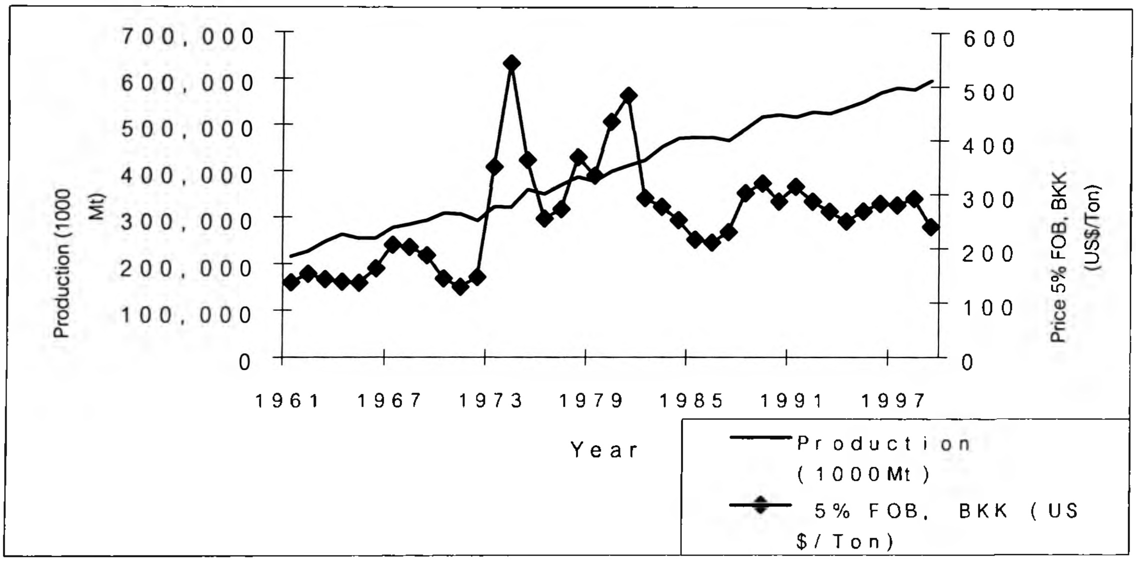
Although the production growth has slowed in recent years, the downward trend in real rice prices is still continuing. This unfavorable situation directly influences a main rice-producer and exporter like Thailand. The production environment in Thailand must be improved in order to cope with the high competition from the new main rice-producers and exporters like India, Vietnam and China. Specifically, Vietnamese and Chinese farmers have responded favourably to economic liberalisation policies introduced in recent years, bringing the two countries from an importer status to the world's fourth and fifth largest exporters respectively.

Table 2.5 Average Percent Share of Rice Imports by Region, 1961-1999

Importing Region	1961-70	1971-80	1981-90	1991-95	1996-99
Asia	69.56	58.39	43.67	42.90	50.67
-East+South-East Asia	33.06	32.33	13.21	12.09	22.01
Africa	8.91	15.15	24.53	23.43	14.30
Europe	11.31	13.81	15.74	14.40	12.66
America	5.84	7.46	9.98	17.00	15.72
Others	4.38	5.19	6.08	2.27	6.65
Total	100.00	100.00	100.00	100.00	100.00

Source: FAO: www.fao.org

Figure 2. 3 Trends in World Rice Production and Price 5% FOB Bangkok, 1961-1999



Source: Table A.1 and A.5 (Appendix A)

When the price of rice changes, it affects both producers and consumers. The consumers benefit from a lower price as they can purchase staple food-grains with less money or purchase more of it for the same amount of money. Falling prices directly influence farmers, as they obtain less revenue and may face a decline in profits if productivity increases do not compensate for the decline. According to Hossain and Pingali (1998: 11-12), the real rice price in many Asian countries has fallen faster than the unit cost of production. However, this has not led to decline on profit per unit of output in many cases because of the adoption of modern rice varieties that enabled farmers to increase rice yields from 1.5-2.5 ton/ha to 4-6 ton/ha. In recent years, many countries in Asia can obtain rice yields of up to 8 to 10 ton/ha so the income from rice would normally increase despite the decline in profit per unit of output. Thus, increasing rice yields and the promotion of more efficient input use can eliminate the conflicting interests of low-income rice consumers and farmers.

Thailand has a very low rice yield, at about 2.3 ton/ha. The best strategy to maintain the income of farmers, alleviate poverty and to sustain the rice-export share in the world market of Thailand, is to increase rice yields. Therefore, policies which encourage rice yield growth should be strongly supported.

2.4 Input Use, R&D in Rice and Yield

A cross-sectional comparison across selected countries in Asia based upon statistics provided by the FAO, Pingali *et al* (1997) and Barker *et al* (1985: 211), show that rice yields are positively related to the percentage of area under modern high-yielding varieties, the proportion of irrigation ratio (the proportion of irrigated area to rice area), fertilizer use and the intensity of R&D investment in the past (Table 2.6 and Figure 2.4-2.7).

Higher rates of adoption of HYVs are associated with higher rice yield as is shown clearly in Table 2.6 and Figure 2.4. More than 90 percent adoption of HYVs (high level) in Japan, China, and South Korea has resulted in rice yields from 5.8 to 6.3 ton/ha, while a 50-90 percent of adoption of HYVs (moderate level) in Indonesia, Philippines, Vietnam, Bangladesh, and India are related to a rice yield of between 2.6 and 4.3 ton/ha, and less than a 50 percent of adoption (low level) in Thailand, Nepal and Pakistan resulted in rice yields of only 2.0 to 2.4 ton/ha.

Similarly, a high irrigation ratio (93-100 percent) in Japan, China, South Korea and Pakistan corresponded to a high level of rice yield (2.3-6.3 ton/ha), the moderate level of irrigation ratio (53-72 percent) in Indonesia, the Philippines and Vietnam related to the moderate level of rice yield (2.8-4.3 ton/ha) and the low level of irrigation ratio (less than 50 percent) in Bangladesh, India, Nepal and Thailand correlated to a low level of rice yield (2.0-2.7 ton/ha) (Table 2.6 and Figure 2.5).

Fertilizer use is also related to the level of rice yields as is shown in Table 2.6 and Figure 2.6. A high level of fertilizer use in rice production (278-475 kg/ha) in Japan, China, South Korea resulted in high levels of rice yield (5.8-6.3 ton/ha), whereas moderate levels of fertilizer use (119-152kg/ha) in Indonesia and the Philippines resulted in moderate levels of rice yield (2.8-4.3 ton/ha) and low level of fertilizer use (less than 100kg/ha)) in Vietnam, Bangladesh, India, Nepal, and Thailand resulted in a low level of rice yield (2.0-3.2 ton/ha).

A comparison of selected Asian countries, based upon statistics provided by the UN and Evenson and Flores (1978), show that South Korea, the Philippines, and India were deemed to have a high level of R&D investment in rice in the past, while Nepal and Indonesia were found to invest at a moderate level. Thailand was classed as having a low level of R&D in rice along with Vietnam and Bangladesh. However, the intensity of agricultural R&D, which is calculated from the ratio of agricultural R&D expenditure and value added in agriculture in 1980, showed that Thailand had higher ratio than Nepal, Bangladesh, India, Indonesia and the Philippines, but lower than Japan, China, and South Korea (Table 2.7). This indicates that Thailand has been invested in agricultural R&D at a comparable level, while the share of R&D in rice has been low when compared with other developing countries. This fact was confirmed by Setboonsarng *et al* (1990) who showed that the average share of research expenditures in rice was only about 14-17 percent of total agricultural R&D expenditure during 1973-1990.

Table 2.6 Rice Yields, Use of Modern Inputs in Rice in Selected Asian Country, 1990

Country	Rice yield (ton/ha)	Adoption of modern varieties (%)	Percent of irrigated area	Chemical fertiliser use (kg/ha)
Japan	6.1	100	99	460
China	5.8	100	93	278
South Korea	6.3	100	99	475
Indonesia	4.3	77	72	152
Philippines	2.8	89	61	119
Vietnam	3.2	80	53	98
Bangladesh	2.7	51	22	98
India	2.6	66	44	71
Nepal	2.4	36	23	25
Thailand	2.0	18	27	46

Sources: FAO Production Yearbook, various issues and Pingali *et al* (1997)

Table 2.7 R&D Expenditure in Agriculture and Rice in Selected Asian Countries

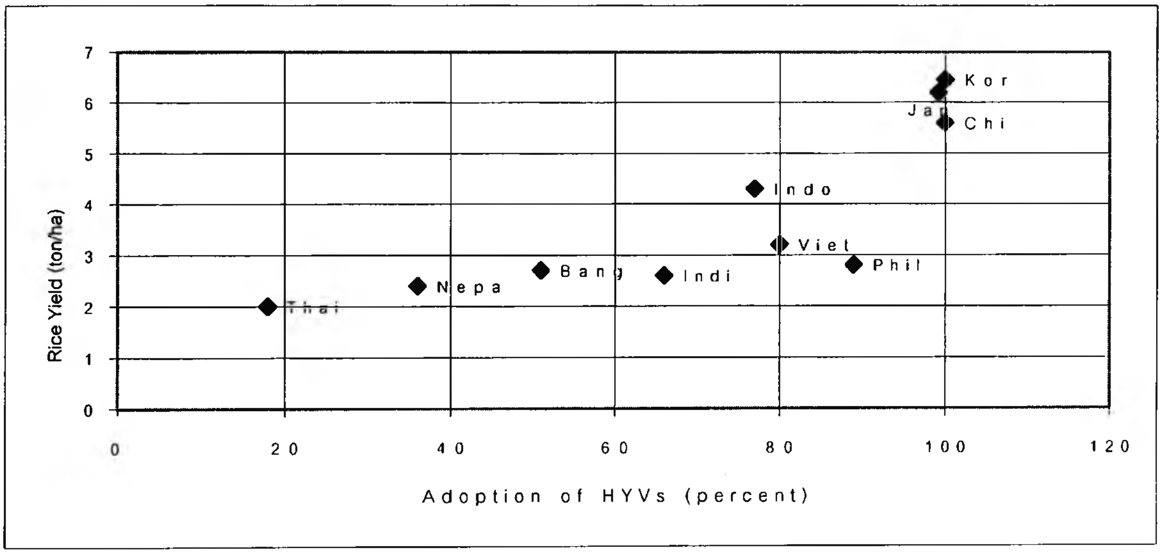
Country	Rice R&D Expenditures per 100,000 ha (Thousand $US)*	Agricultural R&D Intensity **
Japan	-	17.54
China	-	10.60
South Korea	35.70	3.15
Indonesia	6.40	1.77
Philippines	14.00	1.17
Vietnam	3.00	-
Bangladesh	1.20	2.13
India	10.30	2.03
Nepal	8.10	2.34
Thailand	3.50	2.87

Notes: * R&D expenditures in rice in 1974 (constant 1971)from Evenson and Flores (1978)

** Calculated from the ratio of agricultural R&D expenditure and agricultural added value (constant 1980 US$), data from Evenson and Pray (1991)

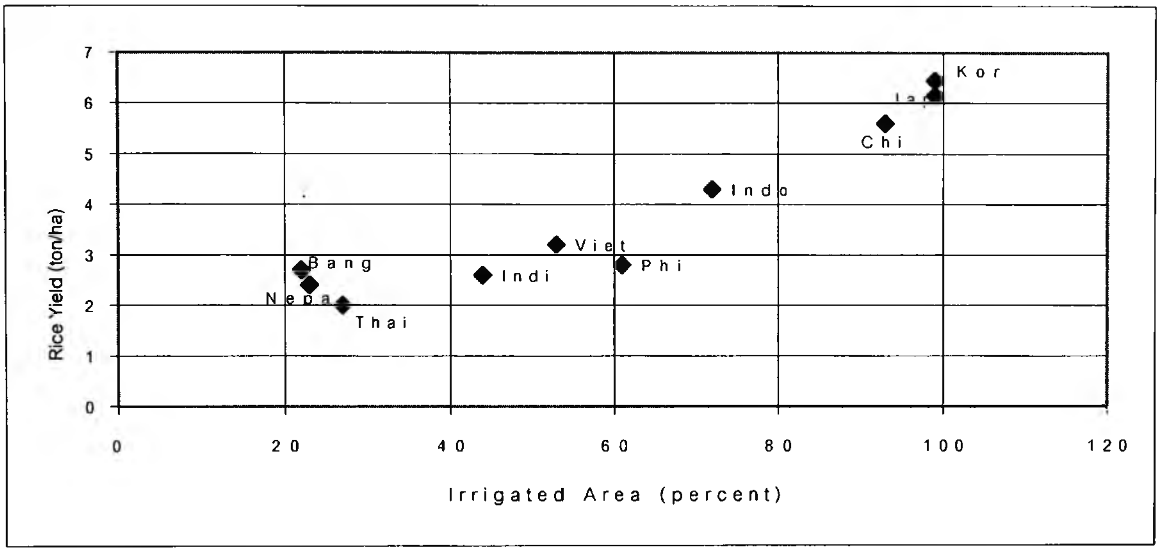
In summary, the strong positive association between rice yields and input uses including R&D investment shown in Figure 2.4-2.7, suggests that Thailand has low levels of rice yield and input use including R&D. This suggests that the very low rice-yield in Thailand is due to the low levels of fertilizer use, irrigated area, and R&D investment.

Figure 2.4 Rice Yield and Adoption of Modern Rice Varieties by Countries, 1990



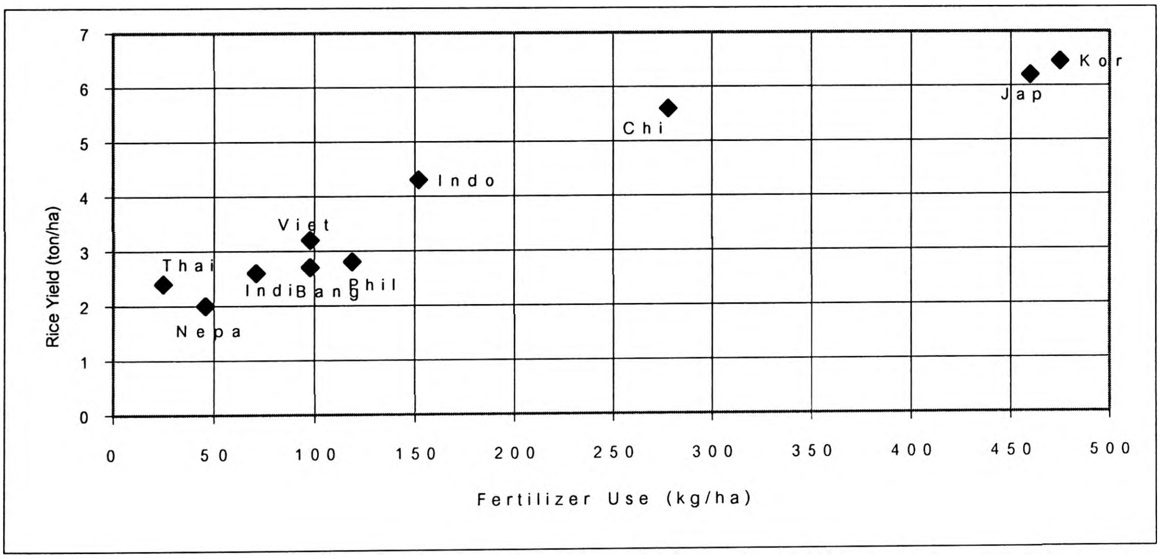
Source: Table 2.5

Figure 2.5 Rice Yield and Irrigation Ratio by Countries, 1990



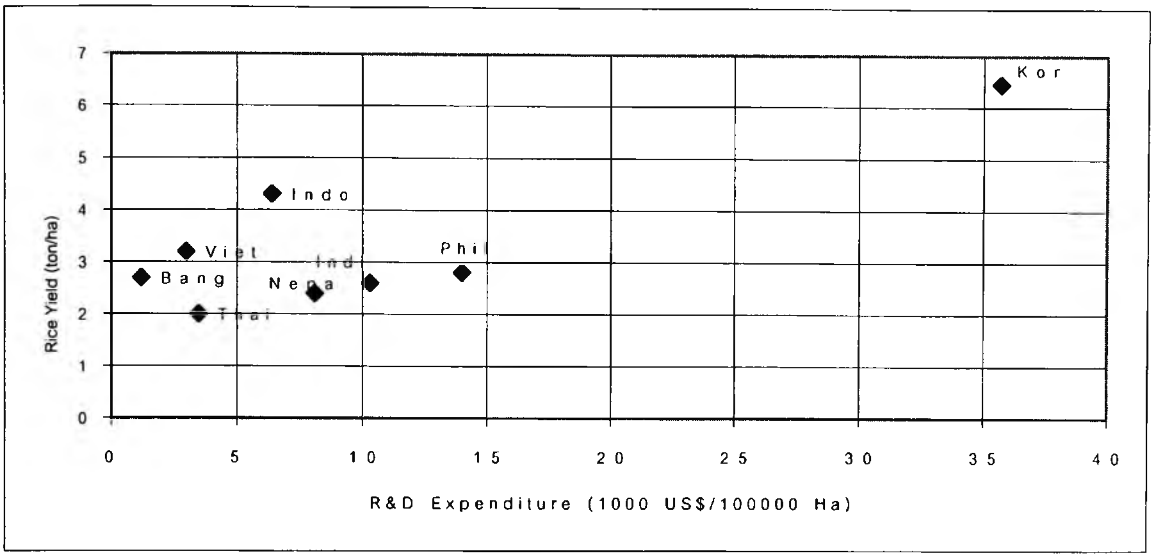
Source: Table 2.5

Figure 2.6 Rice Yield and Fertilizer Use by Countries, 1990



Source: Table 2.5

Figure 2.7 Rice Yield and Rice R&D Expenditures by Countries



Sources: Table 2.5 and Table 2.7

2.5 Conclusion

Although steady growth and gradual structural change in the Thai economy has caused Thai rice to be less important, it still remains the most important crop for Thailand. Over the past four decades, the share of Thai rice in world cultivated area, production, and yield has been gradually changed. The share of rice production has been gradually decreased over time, while the share of cultivated area has been increasing. However, rice yield over the period has grown up slowly.

Thailand is likely to lose its position as a major rice-exporter in the future. The Thai low rice yield trend and high unit cost of the rice production are affecting its comparative advantages. This is due to a change in the rice cultivation environment. Rice-growing countries have followed policy that supports the production of high-quality and favorable-tasting rice for export[4] along with a promotion of high-yielding rice.

When compared to other countries in Asia, the intensification of inputs use and R&D investment in Thailand's rice sub-sector were found to be relatively low. These factors were found to be positively associated with rice yields, as thus require detailed examination which will be described in Chapter 3.

[4] Isvilanonda and Poapongsakorn (1995)

CHAPTER 3

RICE SUB-SECTOR AND R&D IN THAILAND 1967-1998

3.1 Introduction

A preliminary survey of the rice production economy, relevant factors determining rice yield, and R&D in Thailand is presented in this chapter. The chapter is divided into four sections. Section one describes the characteristics of Thai rice production and their major inputs determining rice yield growth. Section two deals with the system associated with agricultural R&D background and organization and R&D expenditures in Thailand. The third section deals with the relationships of rice yield and all relevant determining inputs. The final section relates the trend of rice yield and income generation. The period covered is all relevant time-series data available, focusing on the period of 1967-1998.

3.2 Rice Production Economy in Thailand

3.2.1 Rice Production and Sources of Production Growth during 1967-1998

Over three decades (1967-1998), the rice production of Thailand has gradually increased from an average of 13.18 million tons per year during 1967-1976 to 17.78 tons and 20.67 tons per year during 1977-1986 and 1987-1998 respectively. During 1967-1998, the average growth rate of production was 2.24 percent per annum. However, the growth rate actually decelerated continuously from 4.30 percent (1967-76) to 3.29 percent (1977-86) and 1.80 percent per annum during 1987-1998 (Table 3.1).

Table 3.1 Rice Production, Cultivated Area and Yield in Thailand, 1967-1998

Year	Production (mt)	Harvested Area (rai)	Yield (kg/rai)
1967-1976	13,176.30	44,847.30	292.95
1977-1986	17,775.60	57,344.40	308.96
1987-1998	20,672.67	58,163.17	355.24
Growth Rate (percent)			
1967-1976	4.30 (100.00)	3.43 (79.77)	0.87 (20.23)
1977-1986	3.29 (100.00)	1.16 (35.26)	2.13 (64.74)
1987-1998	1.80(100.00)	0.21* (11.67)	1.59 (88.33)
1967-1998	2.24 (100.00)	1.23 (54.91)	1.01 (45.09)

Source: Calculated from Table A.6 (Appendix A)

Notes: 1) The figures in brackets are percentage.

2) The growth rates are computed by using OLS method.

3) * is not statically significant at 5 percent level.

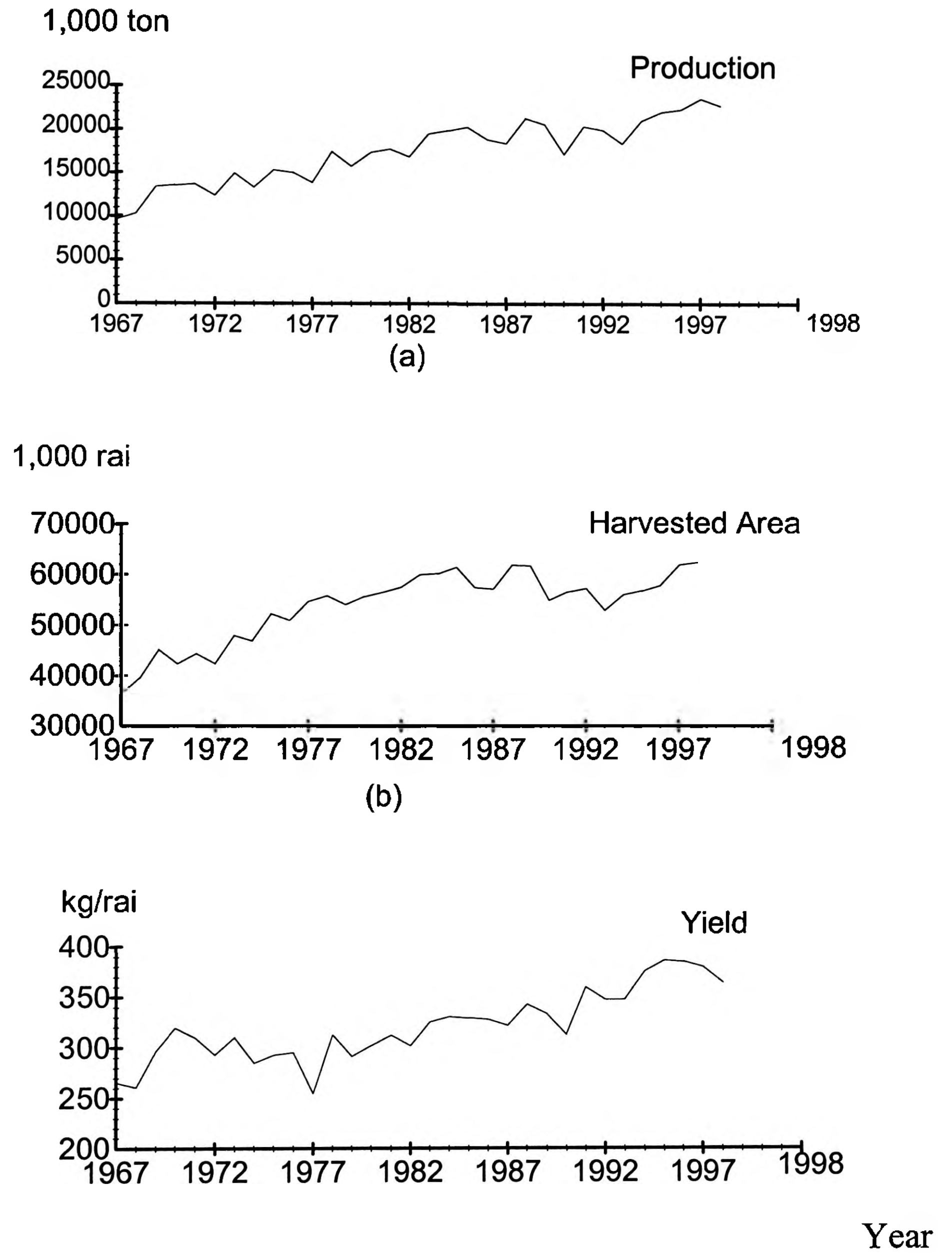
Rice production growth was achieved through an expansion in area and an increase in yield. The average harvested area of rice increased from 44.85 million rai[5] per annum during 1967-1976 to 57.34 and 58.16 million rai per annum during 1977-1986 and 1987-1998 respectively. The total area allocated to rice increased by 1.23 percent per annum during the whole period. However, the yearly average growth rate of area drastically decreased from 3.43 percent during 1967-1976 to 1.16 percent during 1977-1986, and dropped again to 0.21 percent during 1987-1998. This indicates that the decelerated expansion of area for rice is due mainly to the limitation of cultivated area. No further area expansion is to be expected.

[5] 1 rai = 0.16 hectare

During the same period, the average rice yield rose from 292.95 kg/rai during 1967-1976 to 308.96 kg/rai and 355.24 kg/rai during 1977-1986 and 1987-1998 respectively. The annual growth rate of rice yield increased 1.01 percent per annum during 1967-1998. The rice yield growth rose from 0.87 percent during 1967-1976 to 2.13 percent during 1977-1986 and then slightly dropped to 1.58 percent during 1987-1998.

In conclusion, rice production in Thailand has significantly increased almost at an equal rate over three decades during 1967-1998 due to both area expansion and yield improvement at an almost equal rate, approximately 55 percent and 45 percent (Table 3.1). The rice production trend was associated with the harvested area and yield trend (Figure 3.1). Approximately 80 percent of the growth in the first period (1967-1976) was due to area expansion while 20 percent was from yield increase. After that, the percentage shares of the yield growth drastically increased to 65 percent and 88 percent approximately during 1977-1986 and 1987-1998 respectively. Although the annual rice yield growth had increased during 1977-1986, it had decelerated during 1987-1998. The cause of the slow down of rice yield growth will be presented in the next section.

Figure 3.1 Trend in Rice Production, Area, and Yield in Thailand, 1967- 1998



(c)

Source: Data from Table A.6 (Appendix A)

3.2.2 Rice Yield and Variability

In the literature from theoretical and empirical perspectives, yield variability decline has been discussed as an indicator of success in technical progress. Evenson *et al* (1979) expressed concern that new HYVs of crops could increase yield variability in developing countries and recommended doing more research in crops to reduce such variability. The data of Mehra (1981), Alauddin and Tisdell (1988) indicating the coefficient of variation of yield shows a tendency of decline with increased use of modern technology. Moreover, the study of Alauddin and Tisdell used Bangladeshi national and regional data to analyze the impact of new agricultural technology on the instability of food grain production and yield. The intertemporal and cross-sectional regional data indicated that the variability of food grain production and yield has fallen with the adoption of "Green Revolution" technologies.

The purpose of this section is to survey the determinants of rice yield and variability in Thailand for major rice and second rice by using cross-sectional provincial data in 76 provinces throughout the country during 1974-1998. The results of this preliminary investigation are used as an indicator for the success of appropriate R&D policy to stimulate rice yield growth in Thailand.

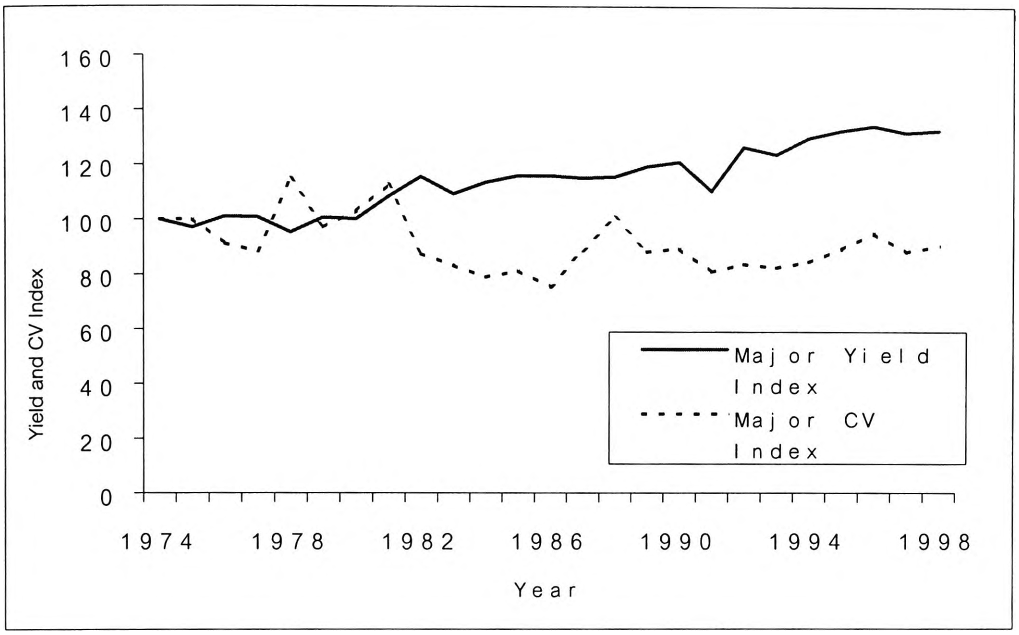
Table 3.2 shows the annual growth rate of rice yield for major, second, and total rice, which has significantly increased over the two periods (1974-1998 and 1980-1998). The growth rate of the major rice yield was higher than that of the second rice yield during 1980-1998 at 1.32 and 1.00 percent per annum respectively. The growth rate of the coefficient of variation CV[6] for major rice decreased

[6] CV is defined as cv = sd/m, where sd is the standard of deviation, m is mean. This CV is well known to be used to measure the deviation of production and yield(Anderson and Hazell, 1989).

significantly during 1974-1998. Although the growth rate of CV for second rice during 1980-1989 has decreased, the average growth rate during 1980-1998 has increased significantly. The trend line of rice yield and CV of major, second, and total rice, are shown in Figure 3.2-3.4 respectively.

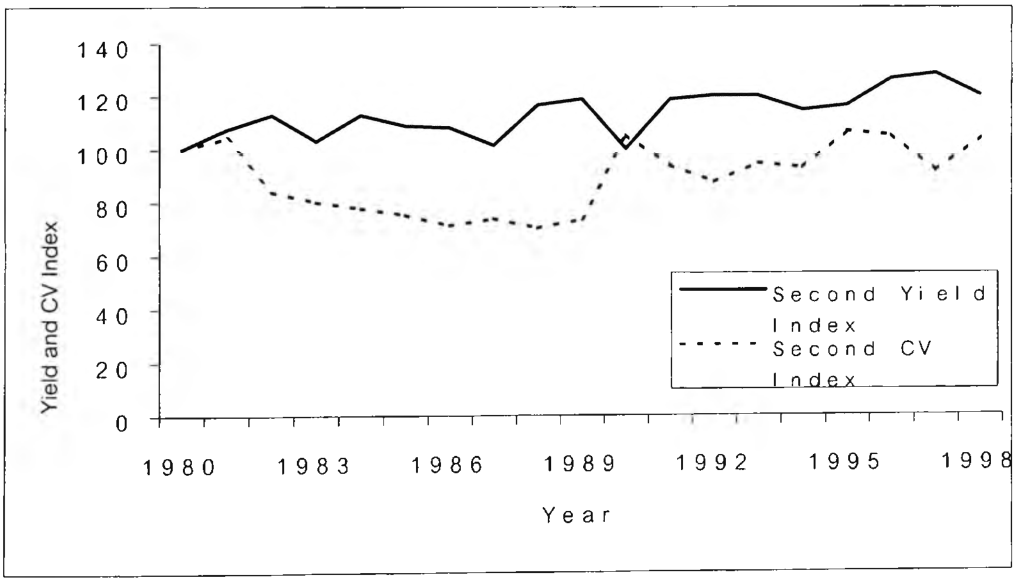
This preliminary analysis based on Evenson *et al* (1979), Mehra (1981) and Alauddin and Tisdell (1988), concludes that the increase of total rice yield along with the reduction of the coefficient of variation during 1974-1998 is probably caused by rice R&D. However, R&D for second rice had been less concentrated than that of major rice because the CV growth rate for second rice during 1980-1998 had a significant positive growth rate at 1.08 percent per annum, while the CV growth rate for major rice during 1974-1998 was a significant negative growth rate at –0.06 percent per annum (Table 3.2). This could explain why the growth rate of average rice yield for major and second rice decreased (from 2.13 percent during 1977-1986 to 1.59 percent during 1987-1998) and experienced a diminishing trend between the two periods (see Table 3.1). This favorable trend in major rice may be due to a successful R&D effort, which has a greater focus on non-irrigated area rather than irrigated area.

Figure 3.2 Major Rice Yield and CV Index, 1974-1998



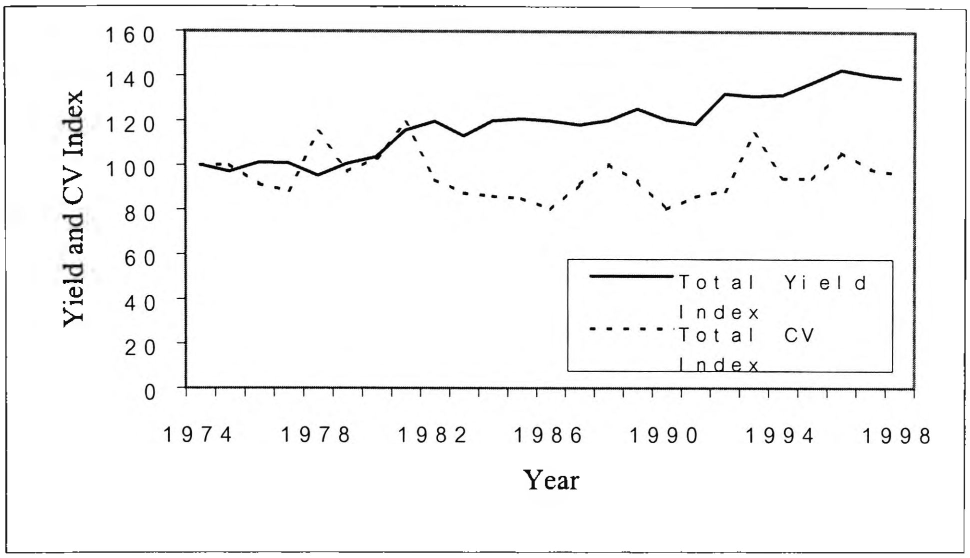
Source: Data from Table A.10 (Appendix A)

Figure 3.3 Second Rice Yield and CV Index, 1980-1998



Source: Data from Table A.10 (Appendix A)

Figure 3.4 Total Rice Yield and CV Index, 1974-1998



Source: Data from Table A.10 (Appendix A)

Table 3.2 Growth Rates of Yield and CV for Major and Second Rice in Thailand during 1978-1998: Cross-sectional Provincial Data

Period	Rice Yield Growth (Percent)			CV Growth (Percent)		
	Major Rice	Second Rice	Total Rice	Major Rice	Second Rice	Total Rice
1974-1998	1.39*	-	1.60**	-0.06*	-	-0.01
1980-1998	1.32*	1.00*	1.37**	-0.03	1.08*	0.02

Source: Computed from data in Table A.10 (Appendix A)

Notes: 1) * and ** are significant at 5 and 1 percent respectively.

2) Growth rates are computed by semi-log method..

However, R&D was found to be one of many factors to increase rice yields. According to previous studies (Fukui, 1978: 258-259; Barker *et al.*, 1985: 73; Isvilanonda and Poapongsakorn, 1995:51-53), rice yield growth in Asia and Thailand was mainly attributed to new technologies (varietal improvement, new methods), chemical fertilizer use, and water control. Each of these factors will be discussed in sections 3.2.3-3.2.5.

3.2.3 Chemical Fertilizer Use

Chemical fertilizer has been used pervasively in rice fields since the introduction of modern varieties of rice in 1969, as HYVs respond well to chemical fertilizer (Fukui, 1978). Total chemical fertilizer use per year in paddies rose drastically from the average of 221,185 tons or 4.55 kg/rai during 1967-1976 to 530,583 tons; and 1,237,388 tons or 8.69 kg/rai and 19.68 kg/rai during 1977-1986 and 1987-1998 respectively (Table 3.3).

The average growth rate of total fertilizer use is a 8.20 percent per annum high over the period. It slightly increased from 4.19 percent during 1967-1976 to 6.79 percent during 1977-1986 and continued to increase to 8.88 percent during 1987-1998. Similarly, the average growth rates of fertilizer use per unit of cultivated area were also high at 6.94 percent per annum for the whole period. It rose from 1.53 percent per annum during 1967-1976 to 5.97 percent during 1977-1986 and continued to increase to 8.24 percent per annum during 1987-1998 (Table 3.3).

Table 3.3 Average Fertilizer Use and Growth Rate, 1967-1998

Period	Average Fertilizer Use (ton)	Average Fertilizer per Cultivated Area (kg/rai)
1967-1976	221,185	4.55
1977-1986	530,583	8.69
1987-1998	1,237,388	19.68
Growth Rate (percent)		
1967-1976	4.19	1.53
1977-1986	6.79	5.97
1987-1996	8.88	8.24
1967-1998	8.20	6.94

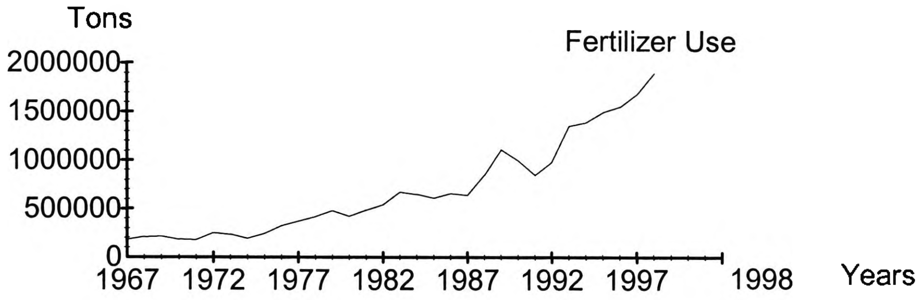
Sources: Calculated from data in Table A.7 and A.9 (Appendix)

Notes: 1)The growth rate are computed by semi-log method.

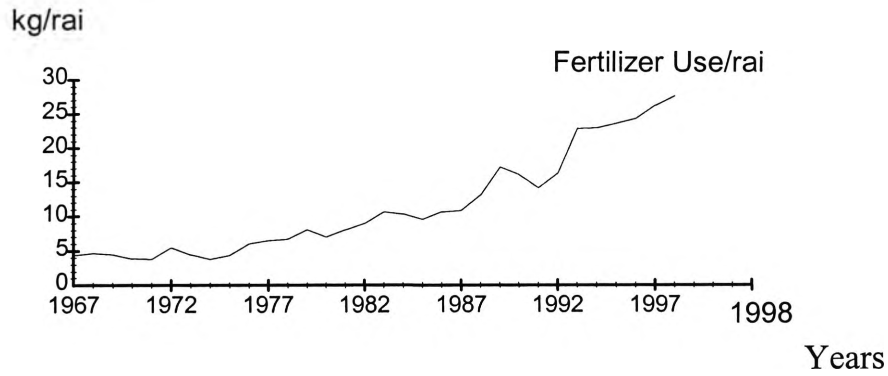
2) All computed growth rates are statistically significant at 5 percent.

Figure 3.5 (a) shows the trend of total fertilizer use has steadily increased over two decades (1967-1987). An increasing trend can be observed from 1987 to 1998. Total fertilizer use in rice production in 1998 was about 2.5 times of that in 1987. Similarly, the trend of fertilizer use per rai {see Figure 3.5(b)}has increased slightly during 1967 to 1987, but increased drastically during 1988-1998. The fertilizer use per rai in 1998 was more than double of that in 1987.

Figure 3.5 Fertilizer Use in Rice Field in Thailand, 1967-1998



(a)



(b)

Source: Table A.7 and A.9 (Appendix A)

3.2.4 Irrigated Area

Modern irrigation in Thailand was first developed in the late 1950's when the Chao Praya Dam project was completed in 1957. The project largely benefited the Central Plain area under the dam site. Since then, the expansion of irrigated area for agriculture has become a significantly important policy of the Thai government. Most of the irrigated area is used for paddy farming (Isvilanonda and Poapongsakorn ,1995). The Royal Irrtigation Department (RID) is responsible for all irrigation in Thailand, except for the People's Irrigation Projects, which are managed by farmers' groups and some pup irrigation schemes operated by the Electricity Generating Authority of Thailand (EGAT). However, all irrigation investments were financed by the government through budget allocation to R&D.

Irrigation development in Thailand was concentrated on the Chao Phraya Plain, which had the greatest potential and highest level of economic development. Other major irrigation developments were the construction of six dams in the Northeastern region and numerous medium scale schemes in the Southern region. However, recently the government has the tendency to concentrate on irrigation investments of medium and small scale projects due to spreading the benefits of irrgation development to poverty areas and to increase the efficiency of existing schemes.

Table 3.4 shows that irrigated area rose from an average of around 12.53 million rai during 1967-1976 to 20.21 million rai and 27.77 million rai during 1977-1986 and 1987-1998 respectively. The irrigated area increased over the entire period with the high growth rate of 3.73 percent per annum. During the same period, the average irrigated area per unit of cultivated area rose from an average of 0.26 rai during 1967-1976 to 0.33 rai and 0.44 rai during 1977-1986 and 1987-1998 respectively. It is a 2.52 percent annually increased average.

The total irrigated area and irrigated area per unit of cultivated area rose with increasing rates during 1967-1976 and 1977-1986, and diminished in the period of 1987-1998. The growth rate of irrigated area rose moderately from 2.91 percent during 1967-1976 to 5.23 percent during 1977-1986 and then drastically decreased to 1.68 percent during 1987-1998. Similarly, the growth rate of average irrigated area per unit of cultivated area rose from 0.28 percent per annum during 1967-1976 to 4.42 percent during 1977-1986 and then decreased to 1.08 percent in 1987-1998 (Table 3.4). The trend for irrigated area and irrigated area per rice area stagnated during 1967 to 1973, accelerated during 1974 to 1985, then declined during 1986 to 1996 (Figure 3.6, a and b).

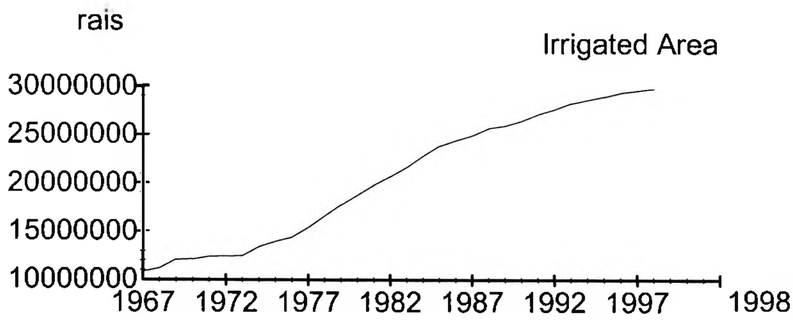
Table 3.4 Average Irrigated Area and Growth Rate, 1967-1998

Period	Average Irrigated Area (1,000 rai)	Average Ratio of Irrigated Area per Cultivated Area
1967-1976	12,534	0.26
1977-1986	20,205	0.33
1987-1998	27,765	0.44
Growth Rate (percent)		
1967-1976	2.91	0.28
1977-1986	5.23	4.42
1987-1998	1.68	1.08
1967-1998	3.73	2.52

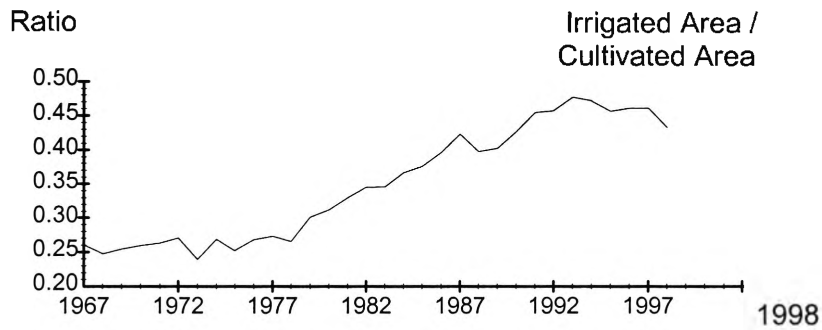
Sources: Calculated from Table A.7 and A.9 (Appendix A)
Notes: 1)The growth rate are computed by using OLS method.

2) All computed growth rates are statistically significant at 5 percent.

Figure 3.6 Irrigated Area in Thailand, 1967-1996



(a)



(b)

Sources: Table A.7 and A.9 (Appendix A)

3.2.5 General Situation of Technology Use in Rice Cultivation

Like many countries in Asia, before the 1960's, Thai farming was more traditional with limited use of chemical fertilizer, limited irrigation and the use of traditional rice varieties. Consequently, statistics for national average rice yields showed that yields followed a downward trend since 1910. However, in the 1960's the declining yield trend appeared to be reversed, and significant increase in yield per rai was achieved (Ingram, 1971 and Fukui, 1978).

There are two principle reasons for this reversal and the rise in yield per rai. Firstly, the introduction and wide adoption of new rice varieties in the 1960's (Fukui, 1978). Secondly, the increase of chemical fertilizer use in rice fields, the progress of mechanization, the improvement of farming techniques and the massive expansion of irrigation and water control for rice fields (Ingram, 1971; Motooka, 1978).

The adoption of high-yielding varieties (HYVs) of rice, which also required increased use of fertilizer, and improvement in water control, resulted in the growth of yield per rai. The increased profitability of both irrigation and fertilizer use caused an expansion of cultivated area for rice beginning in the early 1970's. At present, more than 55 varieties of modern rice including both glutaneous and non-glutinous types have been developed and diffused to farmers in Thailand. The popular RD varieties have been developed from RD1 through RD27 and in recent years the Jasmine 105, recommended by IRR is very popular (RRI, 1999).

In recent years, along with the widespread diffusion of many types of HYV's, chemical fertilizer is widely used for rice production, as the paddy yield of HYV seeds show best response to chemical fertilizer. The average use of fertilizer per unit area of rice per annum has increased from 4.55 kilograms per rai in 1967-1976 to 8.69 kilograms per rai and again to 19.68 kilograms per rai in 1977-1986 and 1987-1998 respectively (Table 3.3).

The increase in the irrigated rice area has also been an important factor influencing rice yield growth in Thailand. During 1967-1976, 1977-1986 and 1987-1998; the average ratio of irrigated area per cultivated area of rice has risen from 0.26 to 0.33 and 0.44 respectively (Table 3.4). The impact of irrigation on rice yield can be easily seen during dry season cultivation. Dry season yields in irrigated areas were approximately two times higher than wet season yields in the second half of the 1980's when the irrigated area increased from 0.33 million ha in 1974 to 0.84 million ha in 1988 (Isvilanonda and Poapongsakorn, 1995).

Besides the rapid adoption of HYV's together with chemical fertilizer use and a massive investment in irrigation, mechanisation in rice farming has also spread rapidly particularly for land preparation. One important machine is a power tiller, initiated by the Engineering Division of the Rice Department and commercially produced since 1969 (Isvilanonda and Poapongsakorn, 1995). At present, there are several types of farm machinery and implements such as rice thresher, small tractor, and water pump that are produced and developed by small workshops and large farm-machinery factories. The farm machinery and equipment were modified from imported materials and redesigned to suit the conditions and environment of each particular area in Thailand. The usage of farm machinery is concentrated in irrigated areas.

In summary, the upward trend of rice productivity since the 1960's was due to the use of modern rice varieties, the expansion of irrigated area, and chemical fertilizer use. The most important factor inducing the increase of improved inputs use in rice fields and the growth in rice productivity, has been researched and developed in rice since the early 1950's.

3.3 Thai Agricultural R&D system

3.3.1 Historical Background of R&D in Rice

The Thai government established its first agricultural experimental station in Bangkok in 1902. It was established to conduct sericulture research in order to improve the quality and reduce the costs of silk products for export. In 1903 the Sericulture Department and the first experimental station was set up. A School for Agricultural Craftsmen was established in 1904 and in 1915 a cotton experimental station was established (Ingram, 1971). This was the first major effort towards agricultural R&D in Thailand.

During the same period, the increase of the world demand for rice and cheap ocean transportation encouraged a regular and large demand for Thai rice. Since then, rice has become a major export of Thailand (Ingram, 1971). However, the price of Thai rice in the world market was lower than that of other countries. This was due to a mixture of various grain sizes and the diversity of Thai rice which seemed to be of a lower quality. It was found that there were at least 4,000 local rice varieties grown in Thailand (Pochanukul, 1992).

In order to increase revenues from rice export, The Thai government's Ministry of Agriculture began to do rice research and extension work to improve the quality of Thai rice. In 1916, the Rangsit station for rice production was established. The work here consisted mainly of collecting indigenous and foreign varieties for testing purposes. The higher quality varieties of rice were distributed to farmers. However, some strains recommended during that period, such as Pin Kaew, met with little success (ESCAP, 1977). Furthermore, the most important factor in the beginning of agricultural R&D development in this period was to prepare people for agricultural development and to expand and establish field crop experimental stations and agricultural education. During the 1930's and up to World War II, a second rice experimental station was established at Huntra, Ayutthaya province. Agricultural experimental stations for field crops were also established in the principle provinces in four regions of the country (Welsch and Tongpan, 1973).

After World War II, rice continued to be the backbone of the Thai rural economy and a major export crop (TDRI, 1988). R&D in rice had not formally begun until 1950. Varietal improvement only involved the selection of indigenous varieties (ESCAP, 1977). Dr. H.H. Love, an expert in rice breeding and Dr. R.L. Pendleton, an expert of soil science from USDA, were sent to Thailand in 1950. A huge number of selected varieties were tested, both in the experimental stations existing at the time and in farmer's fields. Some varieties of rice previously thought to be of high quality were found to have limited yield potential and lacked resistance to viral diseases (Pochanukul, 1992).

Academic research was limited in Thailand before the 1950's and traditional agricultural production techniques predominated. Agricultural services set up by the government did not provide adequate advice and guidance. From the advice of the United Nations, Thailand decided to train a substantial body of professionals, the majority with a practical understanding of crop and animal husbandry, to help the farmer in solving problems (IBRD,1959). During this period, several experts in agricultural science from international institutions were invited to Thailand to give technical assistance in the beginning of agricultural research. Furthermore, in 1952 the U.S. Operation Mission (USOM) supported the project Dr. Love had initiated in 1950, by sending equipment and experts (Mr.E.R. Brooks and Mr. J.R. Thysell) to Thailand. This was the real beginning of rice breeding and research programs in Thailand (Pochanukul, 1992). Thus, modern R&D in rice first developed in Thailand in the early 1950's.

In order to do further crop development research, the Thai government increased the investment budget for rice research. According to Moseman (1977:371), rice breeding and improvement in rice farming technique, has progressed effectively in Thailand since the Rice Department was established as a separate organizational unit. This department was responsible for rice research and extension under the Ministry of Agriculture in 1954. In addition, many irrigation projects were developed during this period to serve the new varieties of rice only compatible with irrigated land.

The establishment of the International Rice Research Institute (IRRI) in the Philippines in 1960 strengthened the R&D activity on rice in Thailand. During this period; Thai research was re-evaluated, hybridization efforts were revived and a number of rice cross-varieties were made (Welsch and Tongpan, 1973). During the 1960's, intensive research work emphasizing breeding for resistance to blast, local diseases and insects was begun. Moreover, deep water rice, grain quality, high-yield, and responsiveness to fertilizer varieties were added to the program of rice research. The outstanding R&D achievement for this period was the development of RD1, RD2, and RD3 varieties, which were released in 1969. Coupled with reasonable high soil fertility and water control, these varieties could increase the yield from 15 to 100 percent more than the conventional varieties (ESCAP, 1977).

However, agricultural R&D policy was geared to produce diversification in agriculture due to the increasing demand for field crops such as maize, tapioca and sugar in the world market. Intensive programs, such as breeding programs were started for various crops besides rice. However, there were important changes to the crop research institution. In 1973, the Rice Department was converted to the Rice Division under the Department of Agriculture. Its budget was drastically cut and some research works were abandoned or combined with other works. Since then, the budget for rice research has not been separated from that of the Department.

3.3.2 Agricultural R&D Organization and Rice Research Institute

Although there are many institutions involved in agricultural R&D, the Ministry of Agriculture and Cooperatives (MOAC) is the main government agency responsible for agricultural research and diffusion of technology. While the Department of Agriculture (DOA) is the main government agency responsible for research and development in food crops, the Department of Agricultural Extension (DOAE) is responsible for distribution of crop production technologies to the farmers. Other departments in the ministry perform both research and extension functions in their concerned fields. For example, research and extension in livestock are under the Department of Livestock Development (DLD) and research and extension in marine and freshwater fisheries are under the responsibility of the Department of Fisheries (DOF). The Royal Forestry Department (RFD) and the Land Development Department (LDD) are also responsible for research and extension in their respective fields.

Furthermore, several universities under the Bureau of University perform agricultural research and extension activities. Kasetsart University establised in 1943 is the oldest and the most important agricultural university, however, the government established new regional universities focusing on agriculture in the mid-1970's. Agricultural research from these universities may be transferred to the concerned departments of the ministry or directly to the local area. However, most of the project researches are not continuous and do not directly generate significant agricultural technologies. Research is only undertaken to solve specific problems in specific areas (Setboonsarng & Khaoparisuthi, 1990).

Although several agribusiness companies conduct their own R&D and extension, such as Chareon Poakapan and Agro-chemical Company; their efforts are mostly concentrated on adaptive research in field trials and testing their products for other crops than rice. There are several other agencies involving in crop research but their research activities are limited (Isvilanonda & Poapongsakorn, 1995:12).

In summary, the Rice Research Institute is the main research institute responsible for research on rice. Tasks of the institute involve varietal improvement, seed multiplication, cultivation practice improvement, post-harvest technology and technology transfer. Six rice research centers and 20 rice experiment stations throughout the country function are under its supervision.

3.3.3 R&D Expenditure Share in AGDP and Value of Crops

Table 3.5 shows that the average percentage shares of AGDP on agricultural R&D expenditure is relatively low, compared to the standard figure identified by the World Bank[7] . The ratios of R&D expenditure on agriculture per AGDP varied from 0.32 to 0.73 percent. Meanwhile the average percentage share of crop value spent on R&D expenditure in different types of crop varied from 0.14-1.52 percent and the percentage of total paddy value spent on R&D expenditure in rice varied from 0.14 to 0.55 percent. Moreover, the R&D expenditures share in rice are less than those in agriculture. During 1965 and 1970, the R&D expenditure share spent in rice research was greater than that in other crops. However, after 1974 the percentage share of R&D expenditures on rice research was less than that in other crops. This indicates that the R&D expenditure in rice was restricted, probably due to the promotion of crop diversification.

Table 3.5 The Percentage of Agricultural R&D Expenditures on Agricultural Value of Crops and Rice

Years	R&D Expenditure on Agriculture /AGDP(percent)*	R&D Expenditure on Crop/Value of Crops (percent)**	R&D Expenditure on Rice/Value of Rice (percent)**
1965	-	0.14	0.50
1970	0.73	0.17	0.55
1975	0.33	0.23	0.14
1980	0.32	0.31	0.16
1985	-	0.46	0.37
1990	0.53	0.88	0.38

Sources: * computed from data in Setboonsarng et al (1990)
** computed from data in Table A.4 and A.7 (Appendix A)

3.3.4 R&D Expenditure in Rice

The data series of R&D expenditures in rice were compiled using many sources. R&D expenditure includes administrative costs, personal costs, materials and equipment. The R&D expenditures during 1950-1958 were collected from ESCAP (1977) and the data for the period 1959-1998 are based on the budgets of Thai Government, as reported in the Royal Thai Government Gazettes. The budget of the Department of Rice during 1959-1972 is used as a proxy for R&D in rice directly. The data series during 1973-1998 is estimated from the budget of Department of Agriculture, which is used as a proxy for R&D expenditure on crops. The R&D expenditure on rice during this period was calculated from the budget of Department of Agriculture multiplied by the ratio of average rice research budget to

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[7] World Bank (1981) set the standard ratio of agricultural R&D on AGDP for developing countries at 1-2 percent.

average budget of the Department of Agriculture. Isvilanonda and Poapongsakorn (1995) estimated the ratios of R&D on rice. These converted R&D expenditures in current prices are deflated by the consumer price index (1987 price) to remove the influence of changes in the prices of R&D inputs and transform them into real terms.

Table 3.6 shows that R&D expenditure in 1987 prices has dropped from an average of 168.18 million Baht during 1967-1976 to 97.57 million Baht during 1977-1986 and recovered to 174.50 million Baht during 1987-1998. The average growth rate of R&D expenditure over the whole period (1967-1998) rose by 0.65 percent per annum. During the same period, the average R&D expenditure per unit of cultivated area has decreased from an average of 3.60 Baht per rai during 1967-1976 to 1.60 Baht per rai during 1977-1986 and then has risen up to 2.79 Baht per rai during 1987-1998. However, the average growth rate of R&D expenditure per unit of area during 1967-1998 is misleading because of the above mentioned fluctuations.

The annual growth rate of R&D expenditure in rice was -15.39 percent during 1967 to 1976 due to the drastic cut in the budget of R&D of rice in 1973 when the Department of Rice merged and the Rice Research Division under the Department of Agriculture was created. During 1977-1986, it increased to the moderate rate of 1.53 percent per annum and then has accelerated to 8.39 percent per annum during 1987-1998. During the same period, the R&D expenditure per unit of cultivated area has increased similarly at -18.42, 0.75 and 7.74 percent during 1967-1976, 1977-1986 and 1987-1998 respectively.

Figures 3.7 (a and b) shows the fluctuating trends of R&D expenditure on rice in total terms and per unit of cultivated area. The trends are downward in the first period (1967-1974) and then gradually recovered to represent slightly upward trends in the second period (1975-1989). During 1990-1996 the two trend lines are represented upward with the high rate of growth.

Table 3.6 Average R&D Expenditure at 1987 Price and Growth Rate, 1967-1998

Period	R&D Expenditure (Million Baht)	R&D Expenditure per Cultivated Area (Baht/rai)
1967-1976	168.18	3.60
1977-1986	97.57	1.60
1987-1998	174.70	2.79
Growth Rate (percent)		
1967-1976	-15.39	-18.42
1977-1986	1.53	0.75
1987-1998	8.39	7.74
1967-1998	0.65	-0.52*

Sources: Calculated from data in Table A.7 and A.9 (Appendix A)

Notes: 1) The growth rate are computed by semi-log method.

2) All computed growth rates are statistically significant at 5 percent.

3) * is not statistically significant at 5 percent level in a semilog growth rate measure.

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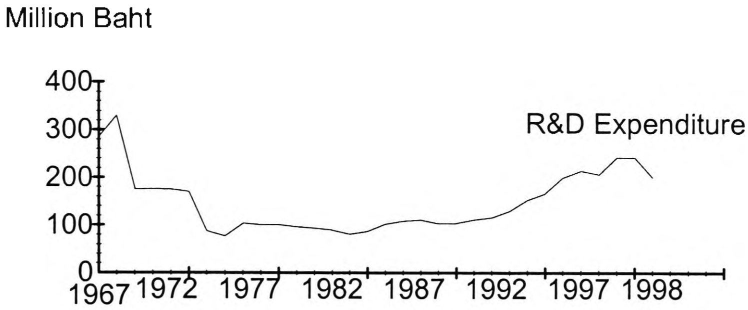
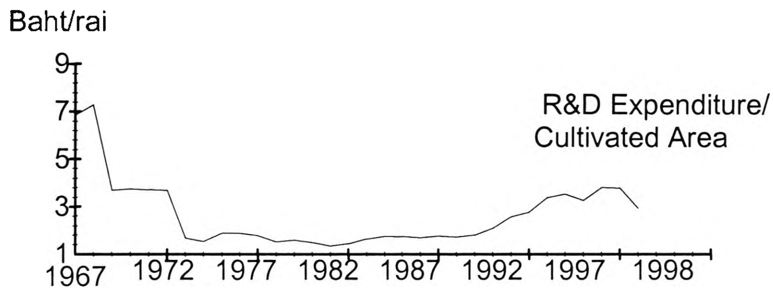
Figure 3.7 R&D Expenditure at 1987 Price, 1967-1998



(a)



(b)

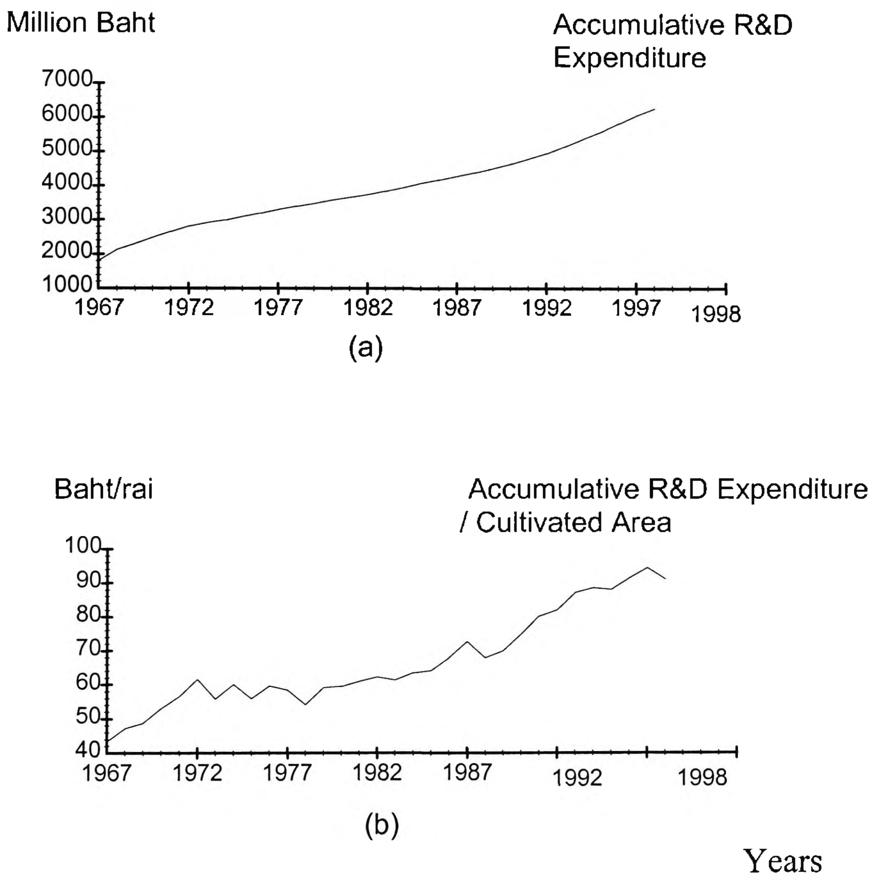
Sources: Table A.7 and A.9 (Appendix A)

According to several studies of agricultural R&D evaluation (see Chapter 4), there are lengthy lag times between the current R&D investments and the flow of R&D benefits in the future. Thus, in this study, R&D knowledge stock[8] or the existing body of knowledge in nominal terms and the capital stock created by accumulated R&D expenditures, are used to compute the accumulation of R&D expenditures in the past. The accumulative R&D expenditures in rice are only computed back to 1950, partly as a result of the lack of data availability before 1950. As discussed above, R&D expenditures on rice before 1950 were not significant

[8] Setboonsarng and Evenson (1991), and Pochanukul (1992) constructed the accumulative research expenditures of the specific forms as a single variable for research capital into their models.

when compared to the R&D investments in the following years. Moreover, according to Welsch and Tongpan (1973: 137), rice breeding work in Thailand began on an intensive scale in 1950. The computed series of accumulated R&D expenditures in rice are shown in Figure 3.8.

Figure 3.8 Accumulative R&D Expenditure at 1987 Price, 1967-1998



Source: Table A.9 (Appendix A)

Table 3.7 shows both the total accumulative R&D expenditures in rice and per unit of rice cultivated area. The average accumulated R&D expenditure has risen from 2,643.46 million baht during 1967-1976 to 3,724.48 million baht during 1977-1986 and 5,155.32 million baht during 1987-1998, with the growth rate at 3.33

percent per annum over the period. The average accumulated R&D expenditure per cultivated area has increased from 54.20 baht per rai during 1967-1976 to 61.20 baht per rai during 1977-1986 and 82.41 million baht per rai during 1987-1998 with a growth rate of 2.13 percent per annum over the entire period.

Table 3.7 Average Accumulated R&D Expenditure at 1987 Price and Growth Rate, 1967-1998

Period	Accumulative R&D Expenditure (Million Baht)	Accumulative R&D Expenditure per Cultivated Area (Baht/rai)
1967-1976	2,643.46	54.20
1977-1986	3,724.48	61.20
1987-1998	5,155.32	82.41
Growth Rate (percent)		
1967-1976	6.00	3.30
1977-1986	2.61	1.83
1987-1998	3.64	3.03
1967-1998	3.33	2.13

Sources: Calculated from Table A.9 (Appendix A)

Notes:1) The growth rate are computed by the semi-log method.

2) All computed growth rates are statistically significant at the 5 percent level.

Figure 3.8 (a) shows that the trend of the total of accumulative R&D expenditure of rice is continuously increasing. This is due to the use of the "stock" approach. Figure 3.8 (b) shows the trend of accumulative R&D expenditure per cultivated area of rice which is increasing with fluctuations associated with the increasing trend of rice productivity.

3.4 The Relationships of Rice Yield and Its Determining Inputs

Although improved water control is primary importance for a steady expansion of rice production, major increase in rice productivity can be also achieved by other factors complementing water control. IBRD (1959) recommended a research program for rice and chemical fertilizer use to help improve rice productivity.

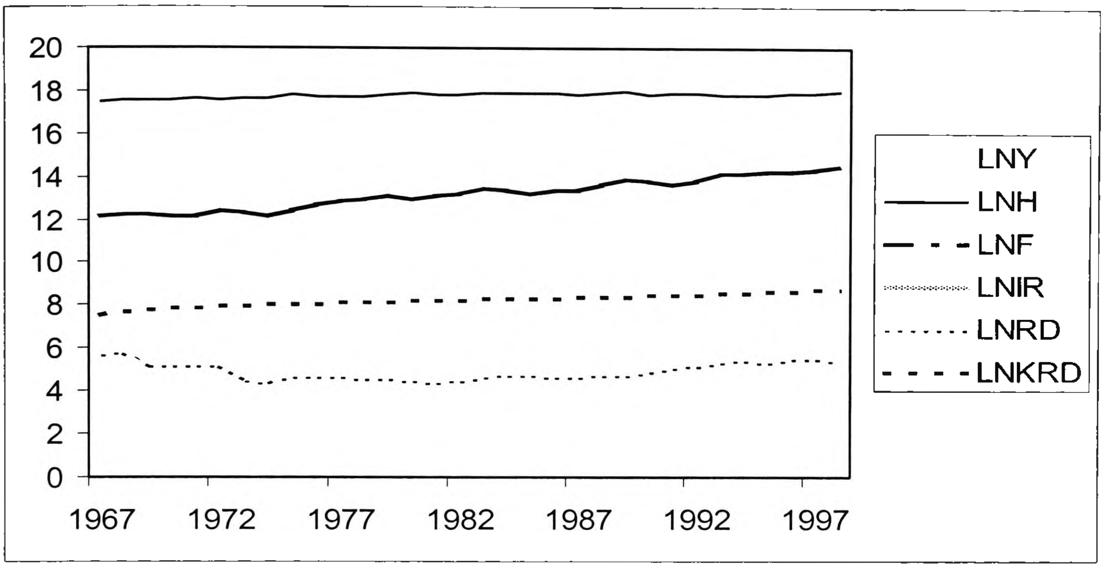
Seed trials under field conditions indicated a possible increase in rice yield of around 15-20 percent. However, yields from improved seeds would be greater and more certain if the seeds were used in conjunction with effectively applied fertilizer under and adequate water control. Results from experiments in fertilizer use vary widely from one locale to another, with variations in the amount of fertilizer used (IBRD, 1959).

From 1910-1954, the average rice productivity in Thailand was continually decreasing. However, from 1958 to 1964, there was a rapid increase in paddy yields. Two reasons can be given for this increasing trend: varietal improvement and the expansion of area under irrigation (Isrankura, 1966: 8-10). After the 1960s, according to Fukui (1978: 258-259); the paddy yields of Thailand increased as a result of the new technique of cultivation, water control and supplementary irrigation, and the high-yielding varieties (HYV's) of rice developed by the Rice Department. The important point to emphasize is the increasing paddy yields are consistent with the growth period of R&D in rice in Thailand.

Although modern rice varieties bred by IRRI during "the green revolution" period in rice production were adopted widely in many countries thoroughout Asia, these varieties were not widely planted in Thailand at that time (Evenson, 1992). It is believed that the domestic effort in R&D on rice by Thailand was a main factor determining rice yield growth in Thailand. Moreover, Welsch and Tongpan (1973) and IRRI (1993:100) mentioned the trade-off between the higher yield and the taste quality; the latter was considered as one of the factor that inhibited adoption of the HYV's. It is clear that the accelerated growth rate of yield between 1977-1998 was closely related to the fast adoption of fertilizer use, irrigation expansion and R&D expenditure in the same period (see Table 3.1, 3.3, 3.4 and 3.6).

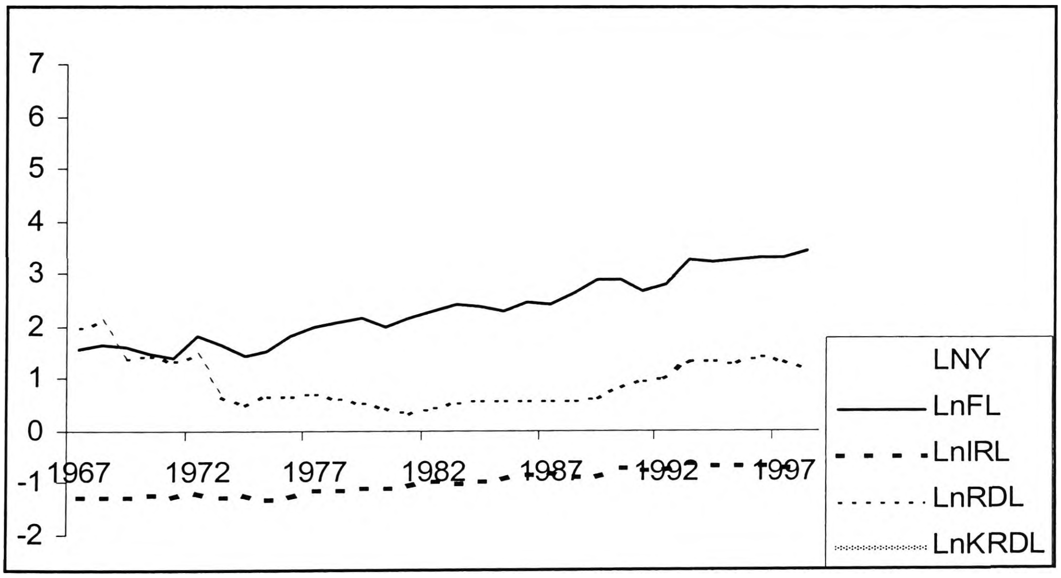
Figure 3.9 and 3.10 show time-series data in logarithmic form of rice yield, fertilizer use, irrigated area, R&D expenditure and accumulative R&D expenditures in Thailand during 1967 to 1998. All time series data have been positively related and moved together in the same direction. It can be seen that the relationships between rice productivity and its determining inputs are associated over the long term period. However, R&D expenditure before 1973 decreased, while accumulated R&D expenditure and rice yield increased over the period.

Figure 3.9 Natural Logarithm of Rice Yields and Explanatory Variables, 1967-1998



Source: Taking logarithm for the data in Appendix A

Figure 3.10 Natural Logarithm of Rice Yields and Explanatory Variables per Area, 1967-1998



LNY = Logarithm of RiceYield
LNFL = Logarithm of Fertilizer Use per Unit of Area
LNIRL = Logarithm of Irrigated Area per Unit of Area
LNRDL = Logarithm of R&D Expenditure per Unit of Area
LNKRDL = Logarithm of Cumulative R&D Expenditure per Unit of Area

Source: Taking logarithm for the data in Appendix A

3.5 Rice Yield and Income Generation

The modern varieties of rice and improved farming practices have had a large impact on world rice production. Most of the increased production is derived from the higher rice yields. Rice yield growth can stimulate wider growth in both the farm and non-farm economy, which in turn can contribute to income generation within and outside agricultural sector.

Although rice yield growth is important for generating income; agricultural R&D and the production of new technology have a profound effect on the agricultural and non-agricultural sector. Expansion of agricultural production and improvement in productivity may contribute to greater income distribution, improved political security and economic stability (Pinstrup-Anderson, 1982). However, the expanded agricultural production is expected to produce lower commodity prices than would have occurred otherwise. Farmers may have problem in net revenue reduction if the marginal productive costs are lower than the output prices.

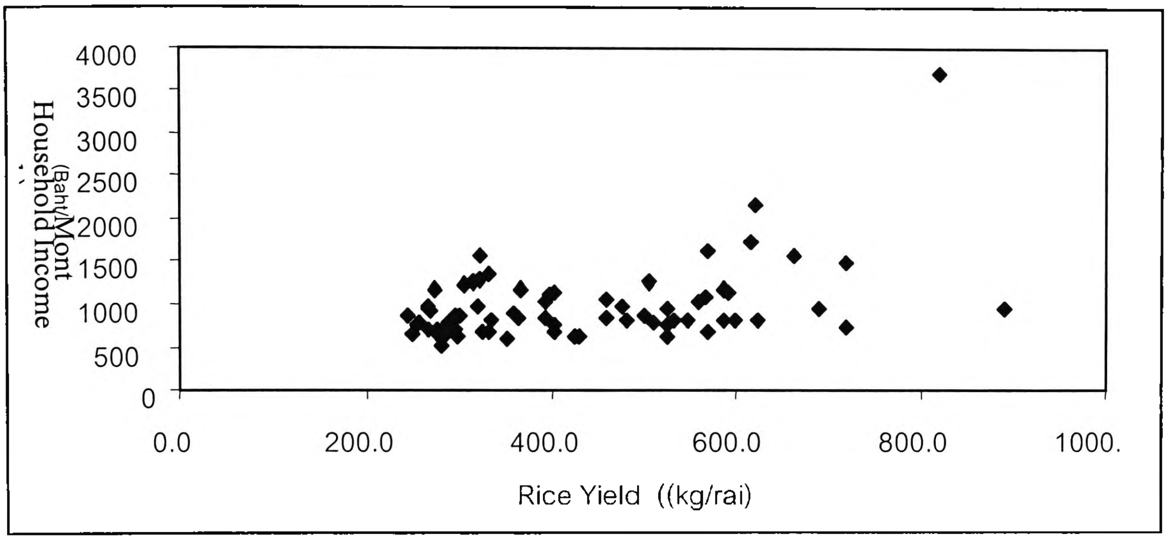
Thus, the primary purpose of this section is to examine the relationships between rice yield and income levels in order to determine whether increasing rice yield supports economic development through income generation. Data from house-hold surveys at a cross-provincial level are used to evaluate how rice yields affected household and per capita incomes in the farm and non-farm economy.

Cross sectional data on rice yields 1996, 1998/99 are from 76 provinces throughout the country are used. Similarly, the cross-sectional data from 76 provinces on household income and per capita income of people in the country in 1996 from 76 provinces are used. The socio-economic censuses conducted by the National Statistical Office (NSO) in 1996 are used to estimate the household and per capita income for each province in 1996. In addition, from household income and farm per capita income in 1998/99 is from the survey by the Office of Agricultural Economics (OAE) conducted in 1999. The two sets of cross-sectional provincial data are scatter plotted to examine the relationships.

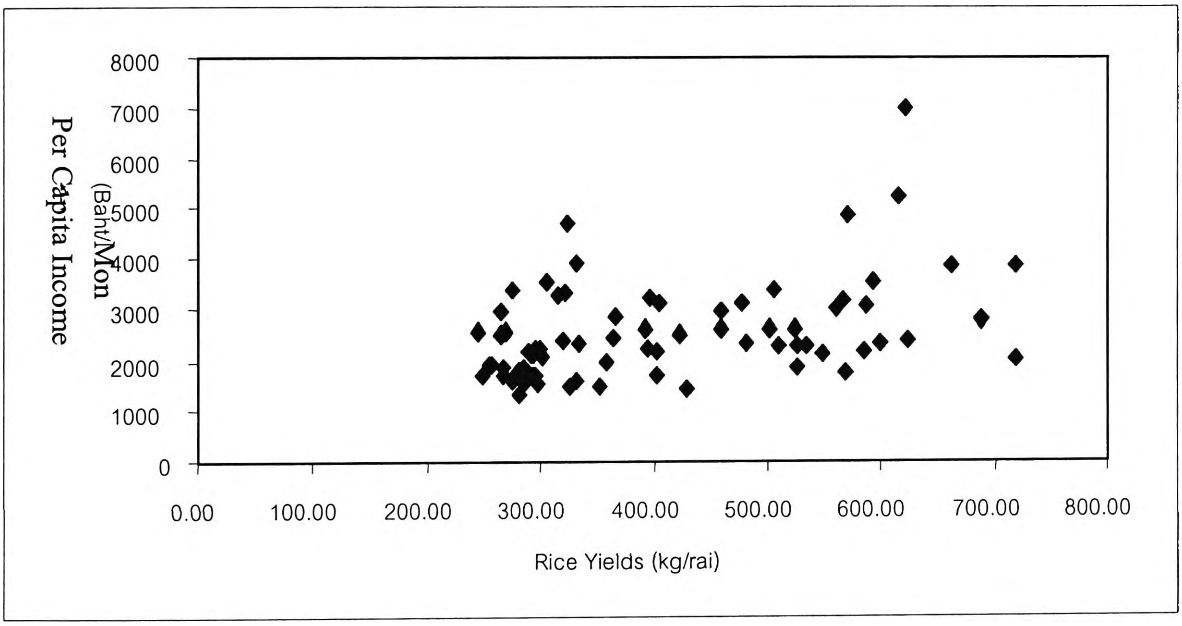
In Figure 3.11 (a), the data for rice yields and household income in 1996, plotted in Figure 3.11(b), the data for rice yield and per capita income in the same year are plotted. The two figures show rice yields are positively related to both household and per capita income. The relationship between rice yields and household income; and between rice yields and per capita income positively showed straight line. It is clear from the scatter diagrams that these two estimating regressions are linear equation.

Similarly, Figure 3.12 (a and b) presents the scatter plotts of rice yields and farmer household income; rice yields and farmer per capita income respectively. As rice yields grow, the observed farmer household income and farmer per capita income have a tendency to increase in positive straight line. Thus, the information in Figure 3.11 (a and b) and Figure 3.12 (a and b) suggests that the relationship between rice yields and income levels should be represented as a simple linear regression.

Figure 3.11: Scatter Diagram of Rice Yield and Income in Thailand, 1996

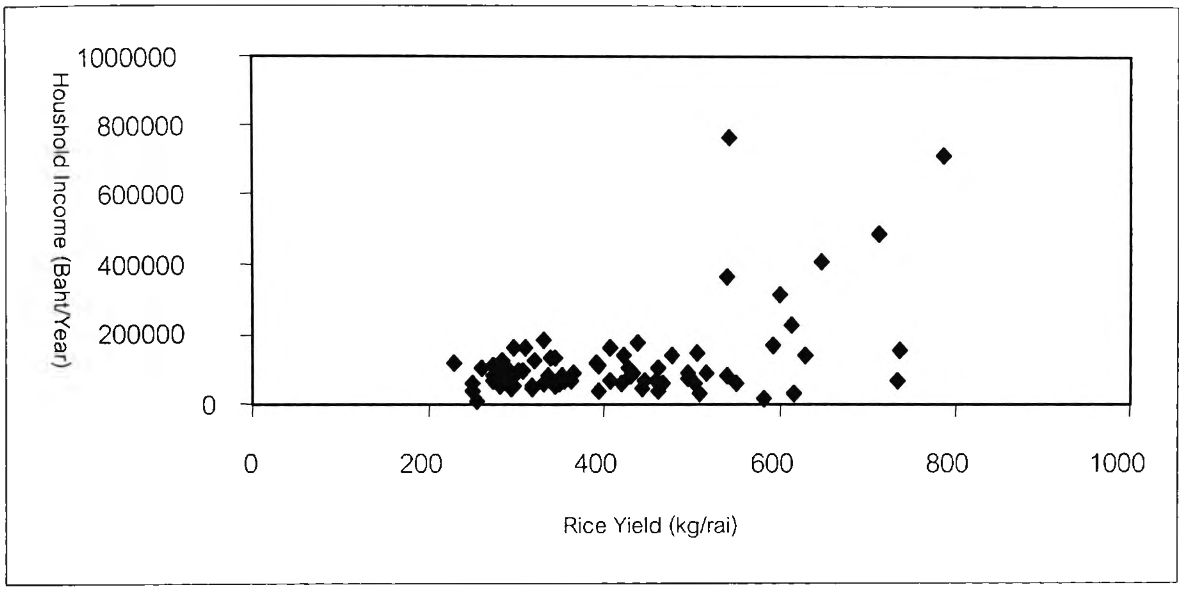


(a) House-hold Income and Rice Yields

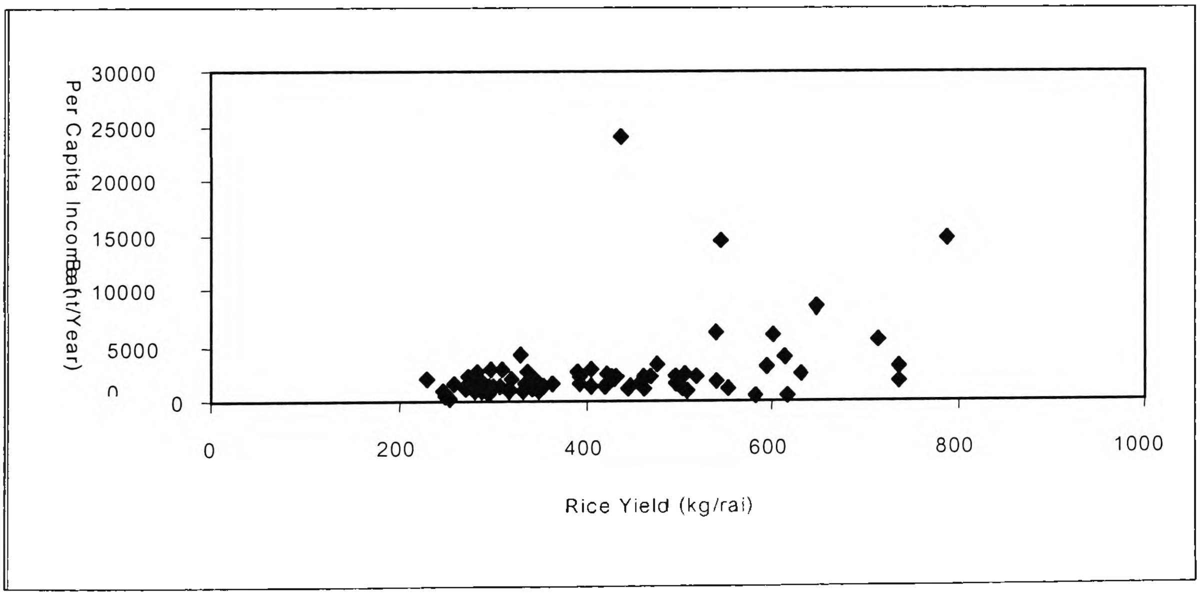


(b) Per Capita Income and Rice Yields

Figure 3.12: Scatter Diagram of Rice Yield and Farmer Income in Thailand, 1998/99



(a) House-hold Income and Rice Yields



(b) Per Capita Income and Rice Yields

Simple linear regressions of double natural logarithm form are estimated by the OLS method. The results are presented in Table 3.8. The results show that although the coefficients of determination (R-bar squared) of the model are not high, all coefficients of the explanatory variables in each model are highly significant and posses the expected signs. The relationships among rice yields and household and capita income for households in Thailand are positively significant at one percent level, with 0.19 and 0.24 of R-bar-squared respectively. Similarly, the positive relationship among rice yields and household and capita income of farmers are statistically significant at one percent level with 0.13 and 0.19 of R-bar-squared. R-squares are low, indicating that there are other important variables besides rice yield generating household and per capita incomes. From this function, rice yield elasticity for household and per capita income are 0.41 and 0.52 respectively. This means that if rice yield increases by 1 percent, household and per capita income increase by 0.41 and 0.52 percent respectively. Similarly, rice yield elasticity for farm household and farm per capita income are 0.87 and 1.09 respectively; meaning that if rice yield increases by 1 percent, farmer household and farmer per capita income increase 0.87 and 1.09 percent respectively. As expected, the rice yield elasticities for incomes are positive, and rice yields affect farmer income much more than income from other sources. These results indicate that the policies to increase rice yield play an important role in economic development, especially in the rural economy.

However, the limitation of such types of simplistic relationships should be recognized because the explanatory power is very low. The interpreting of estimated coefficients may be biased. Moreover, the income of farmers from rice is determined by yield growth, changes in input price, changes in output prices and elasticity of yield input. In fact, the purpose of this section is to roughly indicate the importance of the increase of rice yield to partly stimulate the household and per capita income.

Table 3.8 Relationships between Rice Yield and Incomes

Relationships	No. of Observation	Coefficients	R-Square
1.Household Income	76	0.41 (4.11)**	0.19
2. Per Capita Income	76	0.52 (4.82)**	0.24
3. Farm Household Income	76	0.87 (3.29)**	0.13
4. Farm Per Capita Income	76	1.09 (4.20)**	0.19

Source: Appendix F

Notes: 1. Log linear model estimated with the OLS method

2. Figures in parentheses are t-statistics

3. ** are significant at the 1 percent level

3.6 Conclusion

After a long continous decline between 1910 and 1960, rice productivity has increased since the 1960's. The effort of R&D in rice since early 1950's following the increase of fertilizer use, massive expansion of irrigated area and improved farming practices. A preliminary investigation of relationship between rice productivity and some determining variables reported in this chapter, shows that the increase in rice yield growth experienced by Thailand appears to be related to the increase in fertilizer use and irrigated area associated with the increase of R&D

investment. However, the percentage share of total value of rice spent on R&D expenditure indicates Thailand's investment in R&D for rice was quite low.

Although all relevant time series variables are shown to move together, this issue needs to be addressed. In order to confirm the sources of rice yield growth with econometric methods, the relationships between rice yield, fertilizer use, irrigated area and R&D are investigated in Chapter 6 using cointegration. Moreover, the role of rice yield to stimulate economic development, particularly in generating incomes in the country and in rural sector are investigated. By using cross-provincial data with OLS method, the results indicate that rice yields play an important role to generate household income and per capita income both the whole economy and rural economy.

CHAPTER 4

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

4.1 Introduction

The purpose of this chapter is to create a theoretical framework and review the selected previous works in order to formulate an empirical model and a model estimation detailed in the next chapter. Thus, the first part of this chapter is to present a theory underlining the procedure for evaluating agricultural R&D, including a conceptual framework to explain the nature of technology change, and the contribution of agricultural R&D and technology to economic development in general. In the second part, previous research is reviewed and evaluated using the above theoretical framework. This review is focused on the return to agricultural research and development. Some of the approaches, which evaluate the contribution of agricultural R&D, such as a consumer and producer surplus approach, a cost-benefit analysis approach, and an econometric approach, are presented.

The first part is divided into two sections. Section one describes the basic concepts of the agricultural production function, productivity, cost function, technological change, and agricultural R&D based on the theory of production economics. Section two deals with time lag profiles as an important issue in the evaluation of the contribution of agricultural R&D to productivity, and the concept and methods of the measurement of agricultural R&D efficacy. In the second part, three main approaches to evaluating agricultural R&D: the consumer and producer surplus approach, the cost-benefit analysis approach, and the econometric approach are presented. The conclusion and evaluation of existing literature summarized.

Part 1: Theoretical Framework

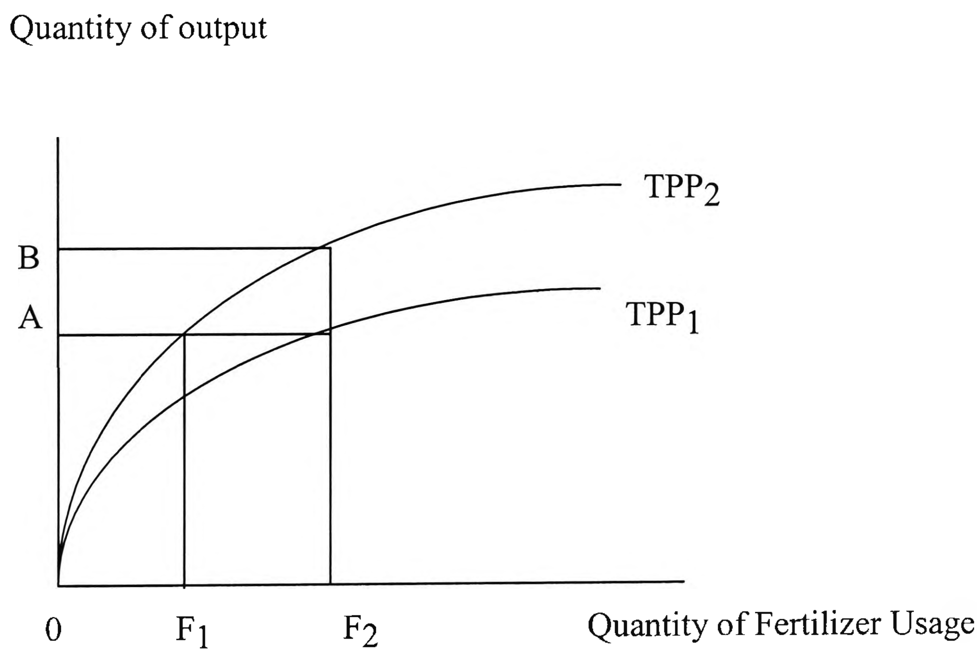
4.2 The Basic Concept of Agricultural Production Function, Productivity, Cost Function, Technological Change, and R&D

The production function expresses the fact that the physical volume of output depends on the physical volume of resource inputs used. It is also dependent on productivity, which is a measure of the efficiency of resources used in the production process. Traditionally, the production function approach has been used to identify the sources of output growth and to estimate the contributions of each source to the growth rate of output.

In the literature, there are two majors sources of output growth: an increase in the supply of factor inputs and technological change. When production grows as a result of an increase in total inputs, it is represented by a movement along the production function, while technological change represents a shift in the production function. It is assumed the firm is working under the condition of perfect competitive efficiency in the production process. A production function gives the maximum amount of product that can be produced at any given time with a given level of technology. The production function can shift over time as a result of R&D.

Generally, technological progress tends to go together as packages of new technology. The inputs are complementary in production when the inputs work. The increased productivity of one depends upon using more of the other. The green revolution, for instance, was heavily dependent on a package of new technologies including HYVs that responded to the use of chemical fertilizers. In Figure 4.1, changes in technology shift the production function upwards, so that more output can be produced from the same quantity of inputs. This means that more of a commodity can be produced from a given level of input use, or the same amount can be produced with fewer inputs. For example, a production function of rice shifts upward if an improved rice variety increases the response of the crop to fertilizer usage. With fertilizer usage increasing from F_1 to F_2, output can be increased from OA to OB. Alternatively, a given output level at OA, can be obtained with a reduced level of fertilizer usage at OF_1 rather than at OF_2.

Figure 4.1 Technological Change and the Total Physical Product Curve



TPP_1 = the total physical product with old technology

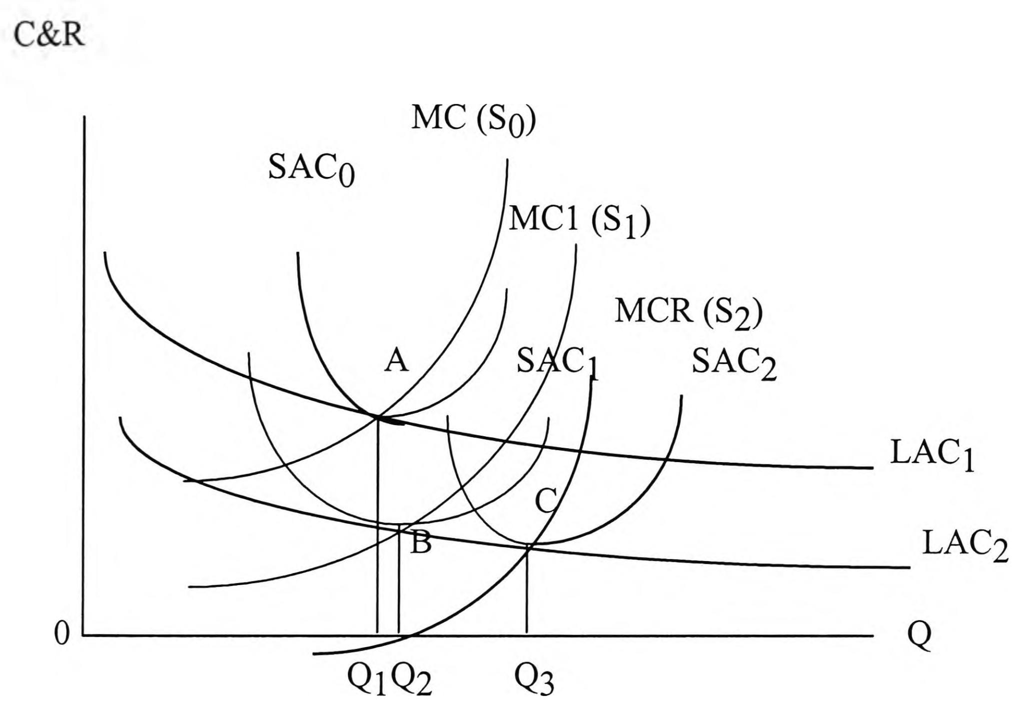
TPP_2 = the total physical product with new technology

The concept of productivity is rooted in the production function. The two main methods of measuring productivity are in terms of partial and multi-factor productivity indexes. Partial productivity measures relate output to a single input, usually labour or land. The partial productivity function (say land productivity or yield per unit of land) is explained by conventional inputs such as capital, labor and new materials, and by novel inputs such as research and extension expenditures. This partial productivity function may be depicted as a yield response function detailed in Dillon and Anderson (1990) and Bickel (1976). Multi-factor productivity or total factor productivity (TFP) is the ratio of aggregate output to an aggregate of all inputs combined. An increase in this ratio implies that more output can be produced with the same amount of inputs used. TFP is used to describe the overall rate of productivity growth as a single series. This accounts for the large number of studies using only non-conventional inputs, such as R&D and extension expenditure to explain TFP, listed in Norton and Davis (1981), Echeverria (1990) and Harris and Lloyd (1991).

The productivity improvement can arise from economies of scale and/or from technological change. While economies of scale occur when the average cost of production falls as the output of the commodity rises, technological change is an improvement in the state of knowledge that enhances the production possibilities. The key sources of technological change are 'learning by doing', and R&D activity. R&D investment creates new knowledge or new technology that is then used as an input to produce outputs. The new technology generated from R&D leads to increased productivity and decreased average cost.

In Figure 4.2, LAC_1 represents the long-run average cost of production before technical change. The move from A on LAC_1 to B on LAC_2, represents the shift of the long-run average cost curve due to R&D investment. The increase in production from B to C along LAC_2 represents the lower costs due to economies of scale. Thus, the increase of output (Q) from Q_1 to Q_3 is the result of two effects: the R&D effect and economies of scale effect.

Figure 4.2 Cost Curve, Economy of Scale and Technical Change



SAC = Short-run Average Cost Curve
LAC = Long-run Average Cost Curve
MC = Marginal Cost Curve

In the literature, the observed output or productivity growth has been measured in many ways. A production function theory states that output is determined by a set of well-specified independent variables ranging from research expenditures to government policies. However, some of the important variables cannot be quantified because of the limitations in available data. Moreover, neither variables is of relative importance. In general, the measurement of technological contribution in terms of output or productivity growth has relied on the concept of an aggregate production function,

$$Q = f(K, L, \dots) \tag{4.1}$$

where Q is the output or productivity, K is the capital, L is the labor, and perhaps one or two other variables included such as research and development expenditures.

The above concept, research and development is included directly as an explanatory variable in the aggregate production function. This means that the nature and extent of changes in technology resulting from investments in research and development can be computed along the measures of research-induced savings in costs or gains in output or productivity. This variable affects agricultural production or productivity either directly or instantaneously. Thus, time lags between the present investment in research and the generation of usable technologies, including the importance of research and development will be discussed as follows.

Research and development encompasses many activities. Research (R) is divided into basic research and applied research. According to the OECD (1970), basic and applied research are defined as follows: "Basic research is original investigation undertaken in order to gain new scientific knowledge or understanding. It is not primarily directed towards any specific practical aim or application. Basic research focuses on the generality of the solution or the concept....Applied research is also an original investigation undertaken in order to gain new scientific or technical knowledge. It is, however, directed primarily towards a specific practical aim or objective. Applied research develops ideas into operational forms." Research and development (R&D) is defined as "creative work undertaken on a systematic basis to increase the stock of scientific and technical knowledge and to use this stock of knowledge to devise new applications."

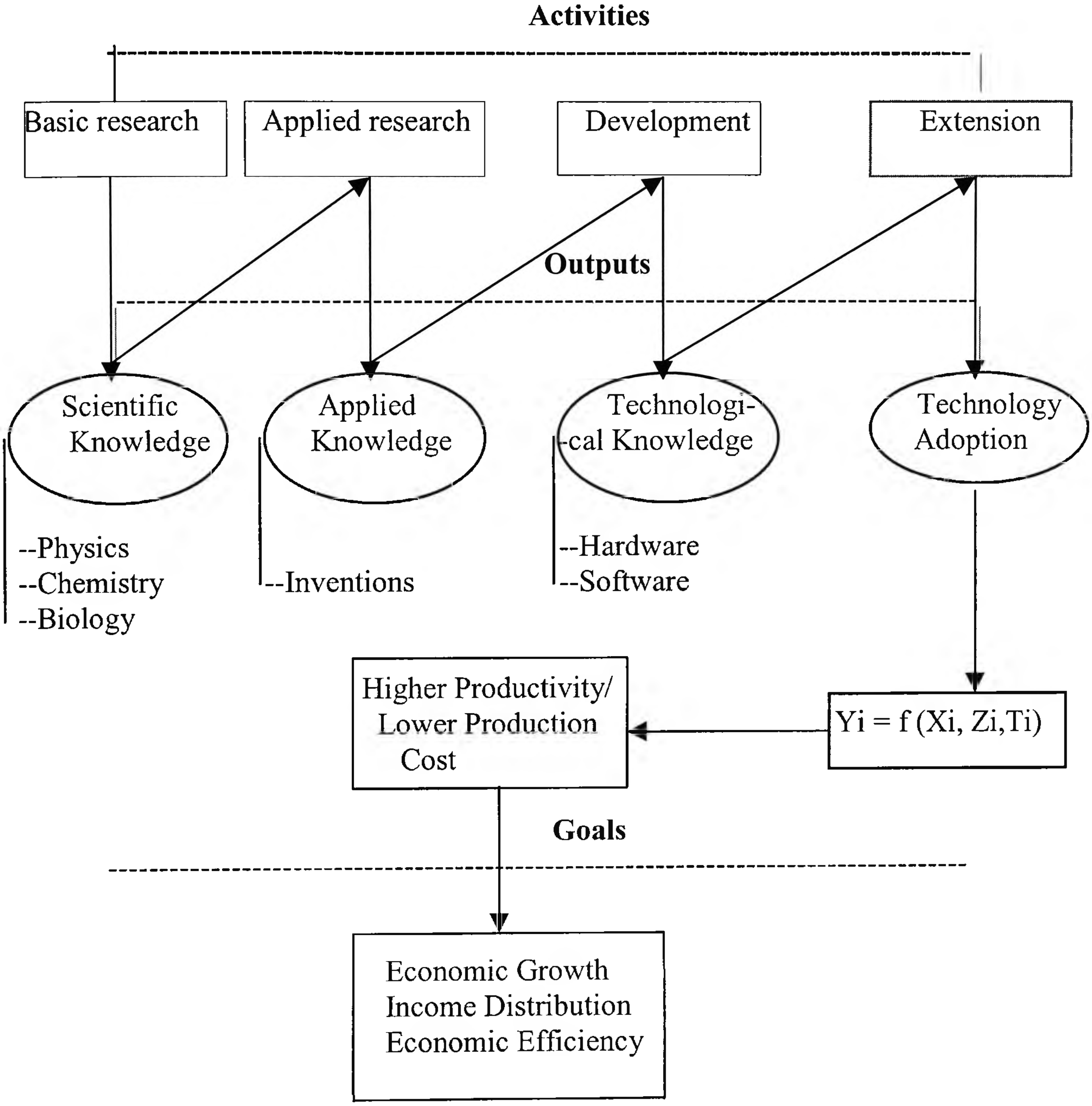
According to Manfield (1969), and Sato and Suzawa (1983), R&D resources are used to develop new and improved products and processes and to advance the stock of scientific knowledge. R&D activity can be classified into three forms: basic research, applied research, and development. The aim of basic research is to acquire scientific knowledge from a natural and social aspect, while applied research and development applies the derived knowledge and constructs new technologies or improves existing technologies for engineering and economic objectives respectively. Although the three forms have different aims, they are closely dependent. Scientists involved in applied research may use basic research results as primary knowledge to extend from. In turn, the results of applied research and development may be used by producers to improve their understanding of nature and society and to be the basis for further research. In general, agricultural R&D includes research in biological or physical sciences, in addition to research on crops, resources, animal husbandry, dairy and fishery enterprises. The final aim of agricultural R&D focuses on innovations, new inputs, product improvement, and operation improvement for agricultural production.

The agricultural technology generated from agricultural R&D is found in both embodied and disembodied forms. Some technologies are embodied in machinery and documents, while some are in the form of modern varieties of plants, improved strains of livestock, and more effective use of fertilizers. Moreover, technological change in agriculture includes new methods of plant cultivation and animal husbandry, and improved managerial skills of the farmer.

From the above definitions, agricultural technology is an essential input in the production of agricultural products. A agricultural technology can be classified into two major groups: a software and a hardware technology. Software technology may take the form of new production processes, for example, a new cultivation, harvesting, or water conservation method. Hardware technologies are concrete objects, new products , for example, new farm machinery, fertilizer mixes, pesticides, new varieties of plants or animals. However, sometimes the software and hardware technology can not be separated. A farm machine, for example, consists of the machine itself and the knowledge necessary to use it.

Figure 4.3 illustrates the stages of activity, the bodies of knowledge and their outputs, and the goals of the agricultural R&D system. The first stage begins with basic research, which leads to an increase in scientific knowledge. This knowledge together with the pool of technological information forms applied research, which leads to inventions. Some of these inventions are selected for development, which produces both hardware and software technology. The diffusion of technology begins through the production process of farmers where technology (T) together with traditional inputs (X) and novel inputs (Z) produce the output. Technological change ,in turn, increases yields and/or reduces production costs. This can encourage the goal of economic development in three distinct ways: (1) stimulating the economic growth through raising farmer incomes and reducing food prices; (2) distributing income to poor people through raising the income of farmers who adopt the technology and increase agricultural wages; (3) increasing economic efficiency due to the decrease in agricultural production costs.

Figure 4.3 Stage Model of Technological Change as a Result of R&D



Yi = Output

Xi = Traditional Inputs

Zi = Novel Inputs

Ti = Technological Change

Sources: Adapted from Rosegger (1980)

Agricultural R&D can be viewed along a continuum from very basic research in the scientific discipline to very specific applied research (Huffman and Evenson, 1992 and 1993). Technological knowledge appears in many forms such as scientists, documents, blueprints, devices, and so on, and can be accumulated like general knowledge, through the process of R&D production. This technical knowledge is not only accumulated, but also can be used as a input to produce new technological knowledge. This implies that the output of R&D can be generated from the process of accumulated R&D knowledge. Finally, this R&D knowledge stock leads to an increase in productivity through technological innovation and production. It must be noted that R&D knowledge stock is created by all past investments in R&D, may depreciate over time, and can be augmented by new investments. An investment in agricultural R&D is an investment in maintaining or increasing the R&D knowledge stock. This knowledge stock may be expanded as a result of persistent R&D; however, the new knowledge may only be used once it accumulates to a certain point.

The above concept can be represented in terms of a production function as shown in Alston *et al* (1998a). It is as follows:

$$Q_t = f(X_t, Z_t, W_t, F_t) \qquad (4.2)$$

where Q_t is agricultural output at time t, X_t is the quality of conventional inputs, Z_t are various infrastructural variables such as public investment in road and irrigation, W_t represents uncontrolled factors such as the weather, F_t is endogenous factors derived from pre-existing knowledge, extension service; human capital in agriculture, and so on. R&D investment can lead to a change in productivity (Q/X) by changing the quality of conventional inputs through an increase in the stock of knowledge.

Generally, the stock of knowledge cannot be observed directly, and therefore the R&D knowledge production function is just a part of the conceptual apparatus. An alternative to the R&D knowledge production function is a reduced-form hybrid of the R&D production function (Alston *et al*, 1998a). This function was used as part of an empirical study to attempt to relate production output or productivity, to lagged values of research expenditure.

Thus, a reduced-form relationship between R&D investments and output or productivity depends on current flows of conventional inputs, uncontrolled factors, and current and past investment in agricultural R&D and extension. This can be expressed as follows:

$$Q_t = f(X_t, Z_t, W_t, R_{t-r}, E_{t-e}) \text{ , r, e} = 0 \text{ to } \infty \qquad (4.3)$$

where R_{t-r} is R&D expenditure for period t-r and E_{t-e} is extension service investment for period t-e. In this model, indefinit long lags of past R&D expenditures and current and lagged extension service investments are used as a substitute for the accumulated knowledge function.

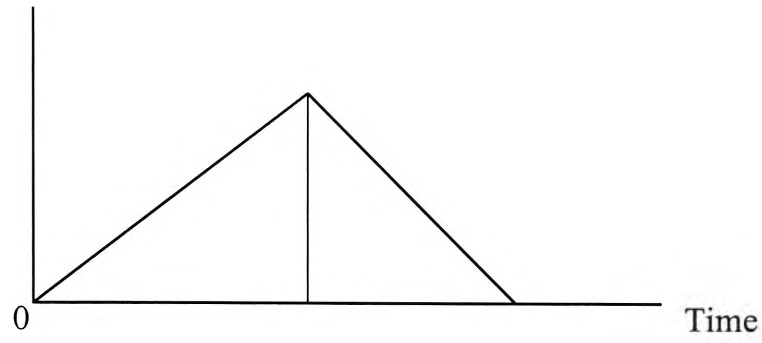
4.3 Time Lag Structure and Measuring the Effects of Agricultural R&D

The major source of variation among production function studies is the time lag profile. This reflects the impact of R&D and extension expenditure on production output or productivity. The early studies on the effects of time lag profile in agricultural R&D expenditure on output by Griliches (1964) used either a single year's lagged expenditure or a simple average of two previous years. To allow for a lag in the effect of the expenditure, Griliches averaged the flow of expenditures in the previous year and the level of expenditure six years previously. Evenson (1967), Fishelson(1971), Bredahl(1975), Cline (1975) estimated the effect of lagged research on US agriculture to be an inverted V-shaped or an inverted U-shaped lag structure, with a mean lag of 6-7 years and the effect declining to zero in the 13^{th} to 14 th year. According to Evenson (1988), the lag profile is different depending on the kind of research (basic and applied) types of commodities, and research output. The distributed lag between R&D expenditure and output or productivity can be classified into four periods: (a) the lag between research spending and research output (b) the lag between research output (new technology) and full adoption (c) the lag period of the growth of the new technology (d) the lag period of depreciation or obsolescence of the new technology. The lag profile of the early studies is presented in Figure 4.4 (a, b and c)

Recently, the lag length has been implemented using modern time-series econometric approaches. According to Alston and Pardey (1996), in theory, a flexible infinite lag of research could be implemented in the production model. In practice, a finite lag might be better approximated by the use of a long finite lag structure. The few studies that have attempted to estimate lag lengths econometrically for aggregate agricultural R&D in USA and UK have found that lag lengths of at least thirty years may be necessary (Pardey and Craig, 1989; Schimmelpfennig and Thirtle, 1994). In the study by Makki *et al* (1999a) using a cointegration approach, the lag length was estimated at 29 years for public agricultural R&D in the USA. Fernandez-Cornejo and Shumway (1997) used an average lag length of the underlying vector auto regression (VAR) from multivariate cointegration tests to calculate the average rate of return to research in Mexican agriculture.

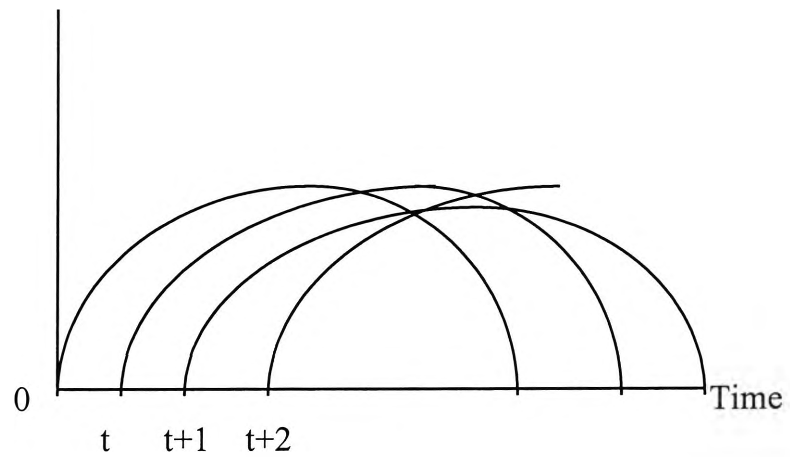
Figure 4.4 Finite Research Lag Structure

Partial Research Coefficient



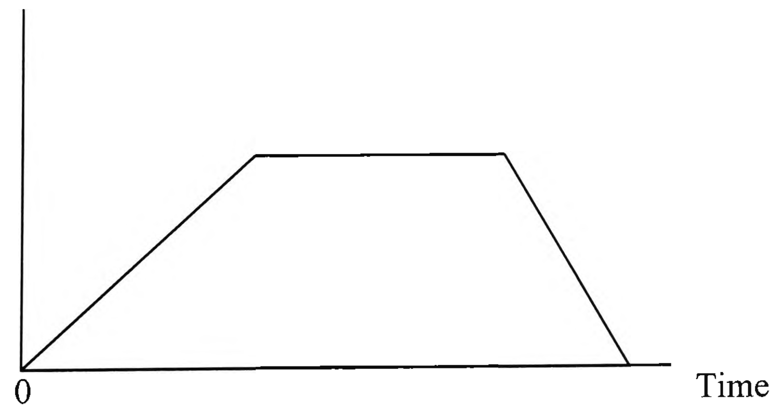
(a) Inverted V-shaped (Evenson, 1968 and Bredahl,1975)

Partial Research Coefficient



(b) Inverted U-shaped (Cline, 1975)

Partial Research Coefficient



(c) Trapezoid - shaped (Griliches)

However, there is no exact agreement in the literature concerning the lag profile. There are disagreements and uncertainties surrounding the magnitude and length of its influence and shape. The use of a finite lag is unclear, and an omission of the knowledge-stock variable can be interpreted as having truncated the research lag. The use of a truncated research lag biased the measured effects of R&D on productivity and rates of return on research (Alston *et al*, 1998a: 24 and 107). Moreover, Alston *et al* (1996: 337) stated "…There are long and variable lags between research investments and their eventual effects on the stock of useful knowledge and production …" Thus, in this study, the current R&D knowledge stock, which is defined by the entire history of changes in the past R&D investments, is used rather than R&D expenditure with a specific time lag.

Agricultural R&D is viewed as an economic investment whereby knowledge is produced through the R&D activities. The production of knowledge needs to be considered like any other investment in that it must compete with other publicly financed projects for funds. Generally, public funds are scarce and are usually insufficient to meet the needs of public spending. Hence, some allocative mechanism is required for the correct distribution of these scarce funds among various types of public interests. Economic techniques can be used as tools to measure the economic effects of agricultural R&D in order to provide estimates that can be used in the decision-making and priority-setting process.

A successful agricultural R&D activity leads to increase in agricultural productivity; more output can be produced with the same amount of inputs or the same amount of output can be obtained from a smaller quantity of inputs. This increase in productivity stems from new or improved products or processes, cheaper inputs, or through other changes in knowledge. Agricultural R&D returns can be computed as the measure of research-induced savings or gains in output or profit.

According to Alston *et al* (1998a), evaluating the contribution of agricultural R&D to economic development involves the following: determining the relationship between the size of the R&D investment and output or productivity, determining the relationship between increases in productivity and the flows of economic benefits, and utilizing a procedure to account for the timing of the streams of benefits. The two broad alternatives used to measure the effects of agricultural R&D in several theoretical and empirical studies are the economic surplus approach and the econometric approach.

The economic surplus approach is a common method for estimating the returns to investment. This approach estimates the flow of benefits from R&D in terms of changes in consumer and producer surplus that result from technological change. These benefits are then related to R&D costs to estimate the rate of return. Consumer benefits are measured as the area beneath the ordinary demand curve. Net changes in consumer welfare as measured using Marshallian consumer surplus. The area beneath the supply curve is a measure of total costs, so changes in the net welfare of producers are measured using producer surplus. (Lindner and Jarret, 1978; Norton and Davis, 1981; Edwards and Freebairn, 1984; Alston et al, 1998a).

The econometric approach involves specifying an explicit functional form. This approach has been used to relate the measure of output, profit, or costs to R&D investment in the past. With this approach, the extent of changes in technology resulting from investments in R&D can be computed along with the R&D-induced savings in costs or gain in output or profit. This approach calculates the returns to R&D by estimating a production function, a cost function, or a profit function.

However, in this study, the production function where output is the relevant dependent variable or response function in which output is defined per unit of a single input (usually land) is used. This approach estimates the relationship between past investments in agricultural R&D and agricultural production or productivity. Economic benefits from R&D have been calculated as the value of the additional output or productivity attributable to the lagged R&D expenditures holding other inputs constant.

Part 2: Literature Review

Since Schultz (1953) developed the "value of inputs saved" approach in the first study to evaluate investment in agricultural research, several studies have followed. Researchers have focused on a wide range of individual commodities and, commodity groups, and projects and programs, at the regional, national, and international levels. Almost all of the studies involving R&D evaluation have shown high rates of returns on these investments listed in Norton and Davis (1981), and Echeverria (1990).

According to Norton and Davis (1981), the major research techniques developed to qualify returns to investments in agricultural R&D can be classified into either *ex post* or *ex ante* evaluations. *Ex post* evaluations can be divided into two major groups: those using consumer and producer surpluses to estimate an average rate of return to research, and those estimating a marginal rate of return to research from the production function. *Ex ante* evaluations can be classified into four groups: those using scoring models to rank research those using benefit-cost analysis to estimate rates of return to research, those using simulation models, and those using mathematical programs to select an optimal mix of research activities.

Alternatively, Echeverria (1990) classified agricultural R&D return studies into two main groups: the economic-surplus approach (consumer-producer surplus, cost-benefit, and index number methods), and the econometric approach (production, profit, and supply function). The first approach calculates return on R&D investment by measuring the change in consumer and producer surplus due to the supply curve shifting to the right as a result of technical change. The second approach sets R&D as a variable in the function and the marginal rate of return on investment are calculated. Moreover, Harris and Lloyd (1991) classified the studies of agricultural R&D return into the traditional approach of estimating consumer and producer surpluses and regression analysis to provide an aggregate production function.

This part attempts to survey the three main approaches used to evaluate agricultural R&D returns[9]. The first approach surveyed is the consumer and producer surplus approach which estimates the average return on investments by calculating the change in consumer and producer surplus due to a shift in the supply curve to the right as a result of technical change. The second approach is cost-benefit analysis, where the individual project costs and benefits are calculated. Cost-benefit analysis technique is also used to calculate the benefit-cost ratio (BCR), net present value of benefits (benefits minus costs), and internal rate of return. The third surveyed approach is the use of econometric methods to determine research (and extension) expenditure as a variable in a production function, and to calculate a marginal rate of return to R&D investment. This approach can be divided into the production function approach, TFP with the production function approach, the dual approach, and the

[9] See Alston *et al* (1998)

cointegration approach. The following sections will review previous studies on agricultural R&D evaluation.

4.4 Consumer and Producer Surplus Approach

This approach estimates the benefit to agricultural research by measuring the change in consumer surplus and producer surplus from a rightward shift in the supply curve due to technical change and measures the increase in the value of output caused by R&D from a given level of conventional inputs.

The concept of consumer and producer surplus was introduced almost a century ago by Marshall (1930). In this method, a total annual benefit from research is derived from the surpluses of consumers and producers. Consumer surplus is defined as the difference between the total value a consumer places on a commodity that a person would be willing to pay for and its actual price, while producer surplus is defined as the difference between total revenue of a producer and the amount received for supplying a unit of the commodity. The simplest surplus model is shown in Figure 4.5. S_0 stands represents a linear supply curve before a research-induced technical change and S_1 represents the resulting linear supply curve. D_0 represents a linear demand curve. The original price and quantity are P_0 and Q_0. After the supply curve shifts due to a technical change, the new equilibrium price is P1 and the new quantity is Q1. The gross annual research benefits is the sum of the changes in consumer and producer surplus, or the area beneath the demand curve and between the two supply curves (area $A_0M_0M_1A_1$). It can be concluded that annual flow of economic benefits is due to the shift in supply from S_0 to S_1.

Although there are several studies using the same consumer and producer surplus approach concept (or index number approach) to estimate an average rate of return on research, there are a variety of formulas and estimated values. These variations are due to differences in the specification of supply and demand functions, and in the nature of the supply function shift. There are six formula[10] to estimate the various total net social surplus due to a supply curve shift which are dependent upon the functional forms and K values[11]. After the total benefit corresponding to the flow of benefits in a particular year due to the supply shift depicted in Figure 4.1, a cost-benefit ratio and a rate of return on R&D investment can be calculated based on the net benefit as the present value of the sum of the consumer and producer surpluses over time.

Schultz (1953) was the first economist to attempt to quantify the returns to agricultural research using this approach. He calculated the value of inputs saved through more efficient production techniques relative to the R&D expenditure. Griliche's (1958) work on the costs and social returns of hybrid corn research in Amercian agriculture followed. Further efforts made by Evenson (1967), Peterson (1967) and others, on social returns have been measured as the change in consumer surplus or area between the old and new supply curve bounded on the top or right by the demand curve.

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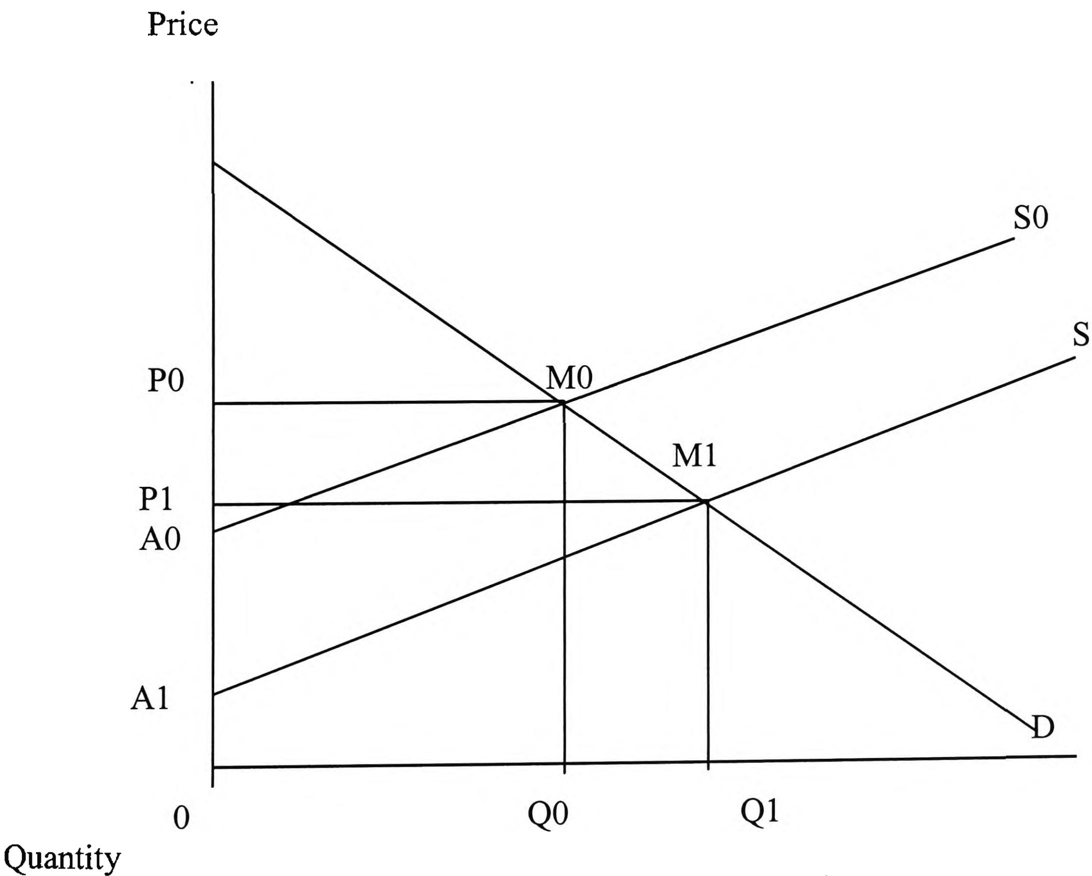
[10] The details of six formulas of estimation the gross research benefits are shown in Norton and Davis (1981).

[11] K-value is the percentage shift in the supply curve, for example, the formula for calculating total net social surplus due to supply curve shift as T.S. = KP1Q1(1 + K/(n +e), where K is the percentage shift in the supply curve, P1andQ1 are equilibrium price and quantity after a rightward supply shift, n the absolute value of the price elasticity of demand, e the price elasticity of supply. This formula was derived from Hertford and Schmitz (1977).

After the 1960's, several empirical theoretical studies followed the consumer and producer surplus approach. Those responsible for the most noteworthy work in the 1970's included Hertford and Schmitz (1977), Lindner and Jarrett (1978), and Akino and Hayami (1975). Hertford and Schmitz (1977) presented a parallel shift of a linear supply curve and calculated consumer and producer surpluses as the areas under the two curves, while Lindner and Jarrett (1978) calculated the gross research benefit by using a pivoting shift of a linear supply curve. With the same method, but different formula, Akino and Hayami (1975) estimated the gross research benefit by using a pivoting shift of a non-linear supply curve. The studies in this period reported mostly high to very high internal rates of return to from research.

Figure 4.5 Gross Annual Research Benefits due to a Linear Supply Shift



S0 = Supply Curve before Technological Change
S1 = Supply Curve due to Technological Change
D = Demand Curve

Source: Hertford and Schmitz, 1977

In the 1980's and 1990's, a large number of studies based on this approach were undertaken. Examples of theoretical studies during this period include Norton *et al.* (1987) who proposed research and development benefits were affected by shifts in demand and government pricing policies. Alston *et al.* (1988) examined the effects of market distortions on the size of research benefits. Miller *et al.* (1988) proposed a link between the form of the supply curve, the type of supply curve shift, and the direction of change in producer surplus. Voon and Edwards (1991) proposed a comparison of research benefits for linear and nonlinear constant elasticity (NLCE) specifications of supply and demand under a pivotal shift in supply. The study suggested the use of NLCE specification and that a pivotal shift in supply is usually preferable to a linear supply curve combined with pivotal shift.

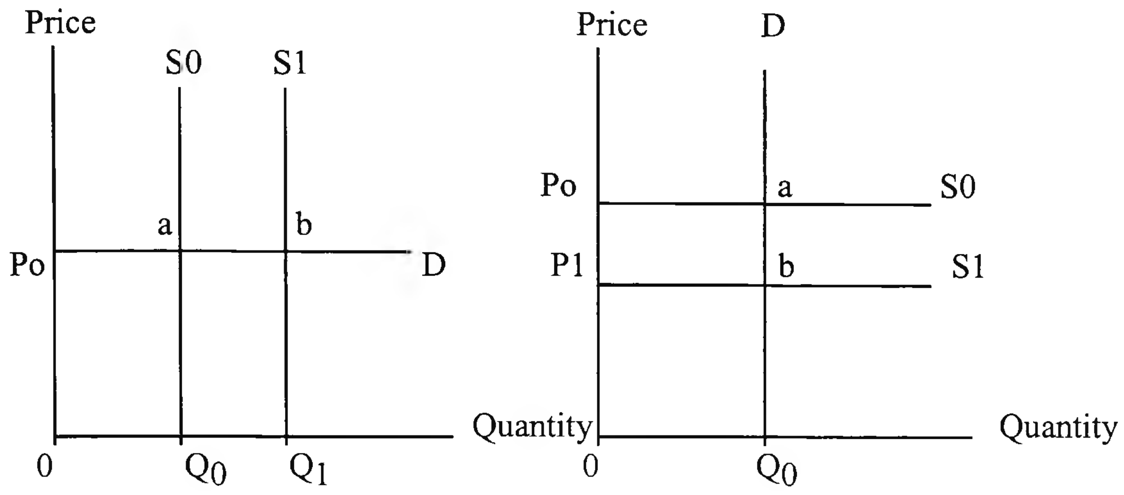
Empirical studies undertaken in the 1980's and 1990's analysed commodities and groups of commodities at national and international levels. Examples of empirical studies in this period are the works of Marsden *et al* (1980) on returns on Australian agricultural research, Scobie (1986) on New Zealand agricultural research, Norton *et al* (1987) on agricultural research and extension in Peru, Harvey (1988) on agricultural research in UK, Widmer *et al.* (1988) on beef research in Canada, Nagy (1991) on returns from agricultural resources and extension in wheat and maize in Pakistan, and Byerlee and Traxler (1995) on analyzing the national and international wheat improvement research in the Post-Green Revolution period. These studies report high internal rates of return to research ranging from 19 to 67 percent.

4.5 Cost-benefit Analysis Approach (CBA)

This approach uses the concept of the economic surplus approach and changes in such surplus measures. Willingness to pay, consumer surplus and producer surplus are the most crucial concepts when measuring social benefit, while opportunity cost is the underlying concept involved when measuring the social cost. A crucial step in CBA is to identify major costs and benefits and then quantify these costs and benefits in monetary terms. In this approach, the individual project costs and its payoffs are estimated. Then benefit-cost ratio (BCR), net present value of benefits, and internal rate of return are calculated to place a value on the increased output or the input saved (cost reduction) due to R&D.

Figure 4.2 (a) shows the increased output is valued at a single market price as the supply curve is assumed to be a vertical line, which shifts against a horizontal demand curve. Figure 4.2 (b) shows the value of inputs saved or the cost reduction at a fixed level of production, where the supply curve shifts down against a vertical demand curve. The gross annual research benefit due to the supply shift from S_0 to S_1 is equal to the area abQ_0Q_1 in the first case, and area P_0abP_1 in the second.

Figure 4.6 Vertical and Horizontal Shift of Supply Curve



(a) The value of extra output (b) The value of inputs saved

Fishelson (1971) first developed the computerized model called Minesota Agricultural Resources Allocation Information (MARRAIS) to collect and process information needed to evaluate research activities. B-C ratios, net present benefit, and internal rate of return (IRR) were calculated by computer to obtain the information need to make relevant decisions. Ramalbo and Schuh (1977) developed and tested a model that focused on growth and distribution effects of technical change along with direct and indirect effects of research. They set four goals for the research program assuming a shift in the supply curve for crops caused by technical change, and discussed the effects of technical change in agriculture on the non-agricultural sector and the effects of economic policies on social benefits and costs of research. Using a subtle variation, Easter and Norton (1977) used scientific estimates of yield and cost effects of various research and expected adoption rates of new technologies to apply CBA to the 1978 university land grant USDA budget. Several subsequent studies have been operated by both individual researchers and research and development institutes. For example, Ruttan (1982), Scobie (1986), and Bottomley and Contant (1988) developed the methods for setting priorities for different lines of agricultural research. Davis *et al* (1987) assessed agricultural R&D from a international perspective. Norton *et al* (1987) studied the potential benefits of agricultural research and extension in Peru. Klein *et al* (1996) estimated the economic returns to yield-increasing research on wheat in Western Canada by using a multi-sector mathematical programming model of Canadian agriculture (CRAM).

4.6 Econometric Approach

The econometric approach involves estimating and specifying a functional form of the links between inputs and outputs. This approach includes lagged research expenditures as variables or inputs in a function. Intended to be used widely and offer a vigorous analysis (statistically) of the impact of research on productivity or the value of output, primal and dual procedures are the two main methods in the econometric approach. The primal procedure involves a production function where output is the dependent variable in the form of value or physical unit or index, response function or partial productivity in which output is specified per unit of single input, and TFP in which output is expressed per unit of aggregate input. The dual procedure involves a profit function or cost function under the assumption of perfect competition. In each function, the primal procedure uses research and extension variables as the explanatory variables, while the dual procedure includes research and extension variables in either a profit or cost function and in the associated systems of factor demands and output supply functions. Furthermore, the econometric approach covers the cointegration approach using modern time-series econometrics. Thus, this approach can be classified into four groups: production function approach, TFP with production function approach, dual approach, and cointegration approach.

4.6.1 Production Function Approach

A major alternative method to evaluate agricultural R&D is the production function approach. This approach treats agricultural R&D (and extension) as a input variable, and the output is some measure of agricultural productivity or the value of the output. Moreover, this approach also allows the marginal rate of return on investments to be estimated. In the literature, the general model of aggregate agricultural production function is as follows:

$$Q_t = A \prod_{i=1}^{m} X_{it}^{\alpha i} \prod_{j=1}^{n} Z_{jt}^{\beta j} e^{ut} \tag{4.4}$$

Where Q_t is an agricultural production or partial productivity (output per unit of a single input) index of an agricultural output, Xi_t are conventional inputs (land, capital, labor, fertilizer, irrigation, and other miscellaneous inputs), Z_{jt} are novel inputs which normally include research, extension services, and farmer education, A is a shift factor, αi is the production coefficient of the conventional input, βj is the production coefficient of novel variables in the jth year, and e^{ut} is an error term.

The production function approach has been widely used as it offers a more rigorous analysis of the impact of R&D on output. This approach involves estimating either a conventional production function in which output is the relevant dependent variable (in the forms of value, physical unit, and index) or a response function in which output is expressed as partial productivity. Furthermore, unlike other approaches this approach explains and highlights the time lag between past investments in R&D and the resulting increase in output. The time lag is considered an essential factor affecting the internal rate of return.

It is assumed the only novel input is research (extension) expenditure, which is considered to impact output or productivity with time lag. Thus, the basic production function model in (4.4) becomes

$$Q_t = A \prod_{i=1}^{m} X_{it}^{\alpha i} \prod_{j=1}^{n} R_{t-j}^{\beta t-j} e^{ut} \tag{4.5}$$

Where Q_t is an agricultural production or partial productivity (output per unit of a single input) index of an agricultural output, Xi_t are conventional inputs (land, capital, labor, fertilizer, irrigation, and other miscellaneous inputs), R_{t-j} is expenditure on research (extension) in the t-j th year, A is a shift factor, αi is the production coefficient of the conventional input, βt-j is the partial production coefficient of research (extension) in the t-jth year, and e^{ut} is an error term.

Griliches (1964) was one of the first economists to attempted to introduce research and extension expenditures directly into an aggregate agricultural production function. In his study, Griliches found research and extension expenditures and education had a significant impact on the level of agricultural output. To allow for a lag in the effect of the expenditure, Griliches averaged the flow of expenditures in the previous year with the level six years previously. Moreover, the results of the study indicated a high social rate of return to agricultural research and extension investments.

With a different model and time lag structure, Evenson (1967) developed a framework specifying the relationship between expenditures on agricultural research and extension, output, and time. Evenson included estimates of the magnitude of the changes in output induced by research and extension by fitting a linear regression function. The study used an inverted V-shaped distribution with a mean lag of six to seven years. The internal rate of return for these estimated marginal products ranged from 54 to 57 percent. The rate became 46 to 48 percent when an adjustment was made for the bias created by the exclusion of a private research variable.

Using the same approach, Peterson (1971) estimated an internal rate of return by assuming a six-year lag between the expenditure and the beginning of a return. He found that if the return is assumed to be internalized, the IRR is around 53 percent. The return is assumed to occur in the sixth year, the rate of return is around 36 percent.

Bredahl (1975) evaluated agricultural R&D return from a single aggregate production function and estimated the marginal productivity of research between states in four major groups of commodities (cash grains, dairy, poultry, and livestock). In the study, the production function for several individual commodities were formulated. The log-linear production function was used, and an estimate of 45 percent was considered to be an appropriate estimate of the internal rate of return to agricultural research.

Cline (1975) was one of the first researchers to employ an econometric model to explain the aggregate productivity index in the United States agricultural sector, and to evaluate the rate of return to public sector agricultural research and extension expenditures. The study concluded that from the estimation of the productivity change model, production-oriented research and extension expenditures injected in year t would affect the productivity following 13 years. The calculated marginal internal rate of return was aroud 26 percent.

Evenson and Kislev (1975) were one the first economists to use the productivity index in agricultural R&D studies for an individual commodity and extrapolate for aggregate production nationally and internationally. They studied the relationship between research and productivity in individual commodities, group of commodities, aggregate agricultural productivity, and international analysis. The study concentrated on measurements and estimations in agricultural research, extension, and productivity. They argued that investments in technological discovery are required for the realisation of significant increases in agricultural productivity. The estimated marginal contributions of research investments have consistently shown higher returns than those realized on more conventional investments designed to produce economic growth.

The remaining debate and further work concerning this approach is concerned with functional form, the lag structure, and data accuracy. Examples in this area include Kahlon *et al* (1977) for work concerning returns to research investment in India, Norton (1981) for work concerning agricultural experiment station in USA , Davis (1981) who proposed the method for calculating the MIRR by using the total and partial values of the VMP of research from the production function, White and Havlicek (1982) for aggregate U.S. agricultural production, Wise (1986) for agricultural output in U.K., and Alston *et al* (1988) who examined the effects of government intervention on the estimated benefits from research.

4.6.2 TFP with Production Function Approach

Aside from the conventional production and partial productivity indexes use, total factor productivity (TFP) is commonly utilized to account for factors such as farmer education, R&D and extension, and weather. The TFP with the production function approach originated from the production function by transforming the value of outputs and conventional inputs into a TFP. The measurement of TFP requires the computation of an index of total output and an index for all factor inputs. TFP is then calculated as the ratio of the index of aggregated outputs to the index of aggregated inputs.

The conventional production function can be applied to both cross-sectional data and time series data; however, the TFP with production function approach can only be applied to time-series data. Therefore, equation (4.5) can be specified in general form as

$$P_t = A \prod_{i=1}^{m} W_t^{\alpha 1} E_t^{\alpha 2} \prod_{j=1}^{n} R_{t-j}^{\beta t-j} e^{ut} \tag{4.6}$$

where P_t is the TFP index, W_t is a weather index, E_t represents a measure of the farmers education level, R_{t-j} is expenditure on research (extension) in the t-j th year, α_1 and $\alpha_{.2}$ are productivity coefficients for the weather index and education level, and e^{ut} is an error term.

Evenson (1988) proposed a two stage method to decompose TFP. Firstly, the productivity index is computed. In the second stage, the TFP index is regressed based on farmer schooling, research and extension, weather, and other variables. After Evenson, several studies followed this approach and included other factors in the model (2.3) such as private agricultural research, human capital, spillover effects, and terms of trade. One study used the same model in different countries with different data sources. Outstanding work during this period included. Jaffe (1989) for R&D spillovers, Thirtle & Bottomley (1988) for estimating and comparing MIRR for

UK agriculture with different types of TFP indices and lag structures, and Thirtle and Bottomley (1989) who estimated the internal rate of return for agricultural R&D in the U.K. during 1965-1980 using Divisia's index number of TFP.

In the 1990's, several important studies used this approach to evaluate R&D in agriculture, integrating one particular commodity or groups of commodities in many countries. Examples of these studies include, Nagy (1991) for wheat and maize in Pakistan, Pray and Ahmed (1991) for aggregate crop productivity in Bangladesh, Salmon (1991) for rice in Indonesia, and McKinsey (1991) for crop productivity in India. Moreover, Thirtle *et al* (1993) constructed indices of TFP for both commercial and communal sectors and estimated the rate of return to agricultural research. Yee (1994) included private R&D and the shifting health of the national economy in his models, Scobie *et al* (1991) proposed a market equilibrium model, and Huffman and Evenson (1992) provided econometric evidence on the contributions of public and private research to U.S. agricultural productivity. Mullen and Cox (1995) used new time series data to estimate the return from research in Australian broadacre agriculture. Alston et al (1998b) proposed aggregate productivity models consisting of an input quantity index, the stock of useful knowledge, and a vector of non-market inputs as the explanatory variables for data on aggregate U.S. agriculture. Evenson *et al* (1999) used TFP growth in Indian crop production and included an irrigation variable, and other public and private investments in the TFP model. All of studies used OLS estimates and reported a high rate of return to investment in R&D.

4.6.3 Dual Approach

The dual approach involves specifying and estimating either a cost function or a profit function that is associated with demand and supply functions. In this approach agricultural R&D (and extension) is treated as a variable in the function as are conventional input and output prices and quantity variables. In the literature, the general model of a cost function is as follow:

$$C_t = c(Q_t, W_t, Z_t, R_{t-r}, E_{t-e}, H_t, U_t) \text{ for } r, e = 0 \text{ to } \infty \tag{4.7}$$

where C_t is the minimum cost of producing output Q_t, W_t is a vector of prices of conventional variable input prices, Z_t is various quasi-fixed factors such as transportation and irrigation, R_{t-r} and E_{t-e} are long lags of past investments in agricultural research and extension respectively, H_t is the stock of human capital, and U_t is uncontrolled factors. The general form of profit function is defined as :

$$\pi = G(P, W, Z, \theta) \tag{4.8}$$

where π reprsents profit, P represents output prices, W is a vector of prices of conventional variable input prices, Z is various quasi-fixed factors, and θ represents the vector of technology variables.

Given the constraint function and objective functions, a functional form such as Cobb-Douglas and translog function is used to capture the effects of R&D and extension. After taking the derivative of the function and setting it to zero, the output-supply and input-demand equations are obtained. The output-supply equations are derived from the derivative of the cost function with respect to output ($\partial C_t/\partial Q_t$ = MC) equal to output price and then the solution for output is obtained. The input-demand equations are obtained by applying Shephard's lemma: $\partial c(.)/\partial Wi,t = Xi,t(.)$. The output-supply and input-demand equations have the same parameters as the cost function. The estimated model gives the total production costs for each year, and the contribution of conventional inputs and R&D to production cost can then be separated. Finally, the parameters from the cost or profit function are translated into measures of a research-induced supply shift.

Several studies have used this approach. The outstanding studies include the work of Huffman and Evenson (1989), Evenson and Quizon (1991), Setboonsarng and Evenson (1991), Evenson (1991), Fuglie (1995), and Khatri et al. (1996). Huffman and Evenson (1989) were the first to develop the dual relationship used to derive a set of supply and demand equations. In this study, the social rate of return to public crop research was high at approximately 62 percent. Evenson and Quizon (1991), Setboonsarng and Evenson (1991), and Evenson (1991) provided comparative insight into technology, infrastructure, output supply and factor demand in India, Philippines, and Thailand. The estimated MIRR for all three countries are high, roughly 40 to 72 percent. Fuglie (1995) proposed a multi-market model to explore technical change in a potato project in Tunisia. The rate of return to research on potato storage ranged from 44 to 74 percent. Khatri *et al* (1996) used a profit function to investigate the source of productivity change. In this study agricultural research was incorporated directly in a dual profit function. The estimated MIRR was around 44 percent.

4.6.4 Cointegration Approach

The regressing of a time series variable on another time series variable often develops the problem of spurious regression. This means that regressions using time series data to determine an economic relationship, often give a high autocorrelated residual. Estimated regression models using the time series data have a high R^2, highly significant t-test for coefficients, but very low DW statistics. This problem arises because the time series variables are nonstationary and have strong trends. The high R^2 and t-value is obtained from the presence of a strong time trend, not from a true economic relationship between them. Thus, the cointegration approach is used to avoid this problem, which may provide invalid coefficients.

Since the late 1980's, some studies have investigated the relationship between agricultural production or productivity and agricultural R&D using the cointegrategration and causality approach. These include Hallam (1990), and Schimmelpfenning and Thirtle (1994). A few studies applied this approach to calculate the rate of return to R&D investments. These include Fernandez-Cornejo and Shumway (1997), Thirtle (1999), Makki *et al* (1999a), and Makki *et al* (1999b).

Hallem (1990) was the first to investigate the relationship between R&D and productivity using the cointegration approach. Hallem raised the possibility that using regression, which employed OLS and Almon distributed lags technique to calculate the rate of return to research investment, may be spurious. He applied the concept of cointegration with the CRDW procedure to the data and found the cointegration and Granger causality tests failed to establish any relationship between research expenditures and productivity. Schimmelpfenning and Thirtle (1994) used the Johansen procedure and CRDW to investigate the relationship between TFP and explanatory variables, such as agricultural R&D, extension, farmer education, private sector patents and weather, with UK data. They found a relationship between R&D expenditures and productivity, and a long run relationship between TFP and R&D expenditures. They also found that the R&D expenditure was Granger prior to TFP and TFP was also Granger prior to R&D expenditures. However, the above studies are only formulate cointegration and Granger causality between TFP and R&D,

rather than to calculating the rate of return of R&D expenditures and the returns to agricultural R&D investment.

In recent years, a few studies have applied which approach to calculate the rate of return of R&D investments. Fernandez-Cornejo and Shumway (1997) estimated the long-run effects of research and international transfer of technology on agricultural Mexican TFP using the cointegration approach with the Johansen procedure. The Mexican agricultural TFP model was formed and regressed to domestic agricultural research expenditure and international transfer of agricultural research. The unique long-run relationship between Mexican agricultural productivity, research spending, and U.S. agricultural productivity was estimated. The average long-run elasticity of agricultural productivity to research investment was found to be 0.133. The average annual rate of return to research investment was around 64 percent. Using the same procedure with different R&D variables, Thirtle (1999) formulated a model by assuming the difference between TFP growth in sugar and the rest of UK agriculture was attributed to the R&D and extension expenditures. The rate of return of R&D calculated using Johansen procedure was found to be 11 percent when producer ROR was included and 21 percent when both producer and consumer ROR were included. The conventional methodology, however, calculated a high ROR of 87 per cent.

Makki *at el* (1999a) and Makki *et al* (1999b) estimated the returns to agricultural R&D using the cointegration technique with an Error Correction Model (ECM). This study argued that time series data (public R&D and extension expenditures, private R&D expenditures, farmer education, terms of trade, and commodity programs) has a long-run relationship with agricultural productivity. The internal rates of return were calculated using the stream of marginal products obtained from the cointegration model. Both estimated the IRR at 27 percent for public R&D and 6 percent for private R&D. However, with the same data and the conventional approach (OLS and polynomial distributed lag procedure), the study gave a 93 percent rate of return for public R&D, and 45 percent for private R&D. The study suggests that using a conventional approach to calculate the rate of return to R&D investment may overestimate the actual benefits of research investment.

4.7 Conclusion and Evaluation of Existing Work

The first part aims to present the framework of the theory used to describe the relationship between agricultural productivity and R&D based on the theory of production economics. R&D is considered a knowledge production sector in the economic system. R&D knowledge is generated from R&D activities that have been accumulated as well as depreciated over time. In this chapter, the general concept of R&D knowledge stock is explained, and R&D knowledge stock that is generated from R&D activities is considered as an important R&D variable, as well as R&D expenditure with a specific time lag, to explain productivity.

In the second part, the three main approaches for calculating returns of R&D investment, discussed above, illustrate the continual evolution and refinement involved in the evaluation of theories of agricultural research and extension. The first approach examined the distribution effect on consumers and producers by estimating an average rate of return to research under a supply and demand framework. The cost-benefit analysis approach used the concept of economic surplus both explicitly and implicitly to calculate the internal rate of return, net present value, and benefit-cost ratio. The econometric method has been used to estimate R&D coefficients with production function, productivity function, cost and profit function, and the cointegration approach, after which the marginal rate of return to R&D is calculated. The rates of return on agricultural research have been estimated for single commodity up to the national aggregate level. Many of the early studies focused on agricultural activities in the United States. All of the studies indicated that investments in agricultural research generates higher rates of return than those realized in other public investment projects. Conclusions were similar for a number of other countries. According to Ruttan (1982), the results of most of the studies using the above approaches show internal rates of return to be between thirty and sixty percent.

Although many approaches are used to calculate the return of investment from agricultural research, no singular approach is superior in all situations. As discussed by Martin (1977), Lindner and Jarvett (1978), Fox (1985), Norton *et al* (1987) and Harvey (1988), several studies concerning agricultural R&D returns using the consumer and producer surplus approach are flawed. Araji *et al* (1978) and Holloway (1998) stated that the flaws included an inadequate cost estimation methodology, and a disregard for the price-offsetting effects on agricultural production. Moreover, the deadweight losses associated with taxation, and other revenue sources for R&D are ignored as demand shifts due to population and income level changes. Similarly, the CBA approach of determining the return of agricultural R&D, has been criticized particularly in Australia. Stewart (1995) and Wilson (1996) pointed out some inadequacies in the CBA templates in common use and questioned the rigour of analyses with CBA method[12]. Furthermore, other criticisms of the conventional production function and productivity approach, include the use inferior functional

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[12] See Kingwell (1999) for more discussions

forms in regression analyses, and the spillover effect is almost always ignored generating false conclusions[13]. Finally, applying time series data with OLS to estimate economic benefits when variables are strong and nonstationary, results in strongly biased coefficients due to spurious results (Makki et al, 1999a; Makki et al, 1999b; and Thirtle, 1999). To avoid the above problems, the cointegration approach and OLS method have been selected in this study.

Although there have been a few empirical studies on the relationship between productivity and explanatory variables such as agricultural R&D using relatively modern econometric technique like the cointegration approach, R&D knowledge stock and depreciation have been ignored. In Thailand, a few studies on R&D evaluation in crops and rice have been undertaken. An early paper by ESCAP (1977) on the impact of various rice research projects on rice production using the CBA approach during 1910 to 1970 provided estimated high internal rates of return ranging from 37 to 48 percent. Pochanukul(1986) argued investment in rice research and extension in Thailand have significant positive impacts on land productivity and farm household productivity on the main crop of rice, but the effects on the second rice cultivation are insignificant. Setboonsarng and Evenson (1991) analyzed impacts of crop research on the supply of rice, maize, and other field crops, and input utilization (labor, machinery, and fertilizer) on Thai agriculture. The study found research elasticity on productivity was 0.09, while the MIRR on research investment was around 40 percent. In terms of input, research had an insignificant positive effect

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[13] Further discusion of such criticisms see Alston and Parley (1996), Wohlgennant (1997), Alston *et al* (1998), and Kingwell (1999).

on labor use, a strong and significant positive effect on mechanization, but a significant negative effect on fertilizer utilization. Pochanukul (1992) applied a normalized quadratic restricted profit function to estimate the impact of crop research on farm income and productivity in the crop sector. The study found that a one Baht investment in crop research can increase real farm income by 26.54 Baht. A 1 percent increase in research capital can increase productivity of variable inputs by about 0.10 percent and the MIRR from research investment is around 45 percent.

In conclusion, all previous studies of agricultural R&D evaluation for Thailand have been based on Cost-benefit analysis and the conventional production function with the specific time lag structure on R&D expenditures. However, statistical test was ignored in the cost-benefit analysis method, so the results from this study were not accurate. The results from the conventional production function with the OLS procedure may have led to a biased estimation of MIRR because of spurious regression results. Although there are a few studies on the impact of agricultural R&D on productivity using the cointegration approach, the effects of R&D knowledge stock on productivity have not been included. This study attempts to use R&D knowledge stock and its depreciation as a R&D variable in rice yield response function. The approaches, empirical models, and procedures for this study using cointegration approach and the OLS method are explained in Chapter 5.

CHAPTER 5

EMPIRICAL MODELING AND ESTIMATION

5.1 Introduction

Although there are several approaches to calculate the rate of return on agricultural R&D investment as reviewed in chapter 4, the most popular and applicable method is the production function approach. In this approach, R&D is viewed as an explanatory variable together with other variables in the production function, which determines output or productivity as the dependent variable. The rate of R&D return is calculated using the marginal product of research or the elasticity of output with respect to research.

This study, using time series data to examine the relationships, avoids the problem of spurious regression by using the cointegration approach. The objective of this chapter is to use econometric techniques to investigate the long-run relationship between rice productivity and determining inputs. The Johansen procedure is applied to test the cointegration for time series data use and the OLS method is used to estimate the coefficients in the models.

This chapter is divided into five sections. In section one, the econometric models for empirical study are presented. In section two, the method of unit root tests is presented to identify the properties of the time series data before proceeding on a full course of econometric estimation. In section three, testing for cointegration is applied to investigate whether the time series variables in the models are cointegrated in the system. In the fourth section, the model is estimated using the OLS technique to estimate coefficients of the long-term relationships between rice yield and determining variables including R&D investment. However, the cointegration test does not mention the direction of the relationships of variables. Thus, in the final section, the causal relationship between the determining inputs and rice yield in the short-term is examined.

5.2 Econometric Models

The main purpose of this study is to estimate the elasticities of total rice yields or national rice yields to factors affecting rice yields. The general model[14] employed for this purpose is based on the Cobb-Douglas production function :

$$Q = A \left(\prod_{i=1}^{n} X_i^{ai} \right) H_i^{an+i} \qquad (5.1)$$

Q is the quantity produced, A is the intercept term, Xi represents the factors of production, H is hectarage or harvested rice area, a_i is the elasticities of production, e^u is the error term.

Model (5.1) can be transformed into a yield function by dividing both sides by hectarage (H), as follows:

$$Q/H = A \left(\prod_{i=1}^{n} X_i^{ai} \right) H_i^{an+i-1} \qquad (5.2)$$

Taking natural logarithms, (5.2) becomes

$$Ln\,(Q/H) = LnA + \sum_{i=1}^{n} a_i LnX_i + (a_{n+1}-1)LnH \qquad (5.3)$$

[14] Bickel (1976) presented the yield functions to analyze national rice yield variation, regional productivity differences, and the impact of the "miracle" seeds on national rice yields by Cobb-Douglas production function. He used OLS method to estimate elasticities that correspond to the

According to several studies (Hsieh and Ruttan, 1967; George, 1976; Adulavidhaya *et al,* 1977; ESCAP, 1977:1; Kanivichaporn, 1979: 39; Barker et al, 1985:73; Isvilanonda and Poapongsakorn, 1995:51-53), there are three significant factors influencing productivity growth of rice in Asia. There has been an increase in fertilizer use, the development and adoption of improved varieties of rice (generated from R&D), and an improvement and expansion of irrigation.

Unlike previous rice models, this model encompasses some important factors; however, a fully comprehensive model would include many more variables such as labour, capital, weather, pesticide use, farm machinery, socioeconomic environment, and so on. These factors are noted in the literature on rice but are not included in this study because of the limited data available. Moreover, according to Behrman (1968) and Tsujii (1978), changes in cultivated area by Thai farmers are responsive to product prices and weather condition. Thus, the use of rice yield per unit area as a dependent variable can eliminate the two explanatory variables; product prices and weather conditions, from the empirical models (Pochanukul, 1992:91).

Following Bickel (1976), it is assumed that the response equations of Thai rice productivity are explained by the Cobb-Douglas production function.[15] The full model relates rice yields to fertiliser use in paddy rice, irrigated area, R&D expenditure, R&D knowledge stock, and harvested area of rice. The following rice yield response equations are assumed to have a log linear relationship with these

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respective value of a_i. These elasticities indicate the anticipated impact on national rice yields of a small change in a selected factor assuming other factors do not change.

[115] Bickel (1976) wrote "In rice cultivation, as much with most agricultural production, too much water or fertilizer and too high a temperature are considered damaging to yields. The standard Cobb-Douglas model assume a constant, always positive or always negative marginal factor productivity over the whole range of a factor. "

regressors. The empirical study models are presented by rearranging all independent variables as follows:

$$Ln(Q/H) = LnA + a_1LnF + a_2LnIr + a_3LnRD + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.4)$$

$$Ln(Q/H) = LnA + a_1LnF + a_2LnIr + a_3LnRD + (a_5\text{-}1)LnH \qquad (5.5)$$

$$Ln(Q/H) = LnA + a_1LnF + a_2LnIr + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.6)$$

$$Ln(Q/H) = LnA + a_1LnF + a_2LnIr + (a_5\text{-}1)LnH \qquad (5.7)$$

$$Ln(Q/H) = LnA + a_1LnF + a_3LnRD + (a_5\text{-}1)LnH \qquad (5.8)$$

$$Ln(Q/H) = LnA + a_1LnF + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.9)$$

$$Ln\ (Q/H) = LnA + a_1LnF + a_3LnRD + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.10)$$

$$Ln(Q/H) = LnA + a_1LnF + (a_5\text{-}1)LnH \qquad (5.11)$$

$$Ln(Q/H) = LnA + a_2LnIr + a_3LnRD + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.12)$$

$$Ln(Q/H) = LnA + a_2LnIr + a_3LnRD + (a_5\text{-}1)LnH \qquad (5.13)$$

$$Ln(Q/H) = LnA + a_2LnIr + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.14)$$

$$Ln(Q/H) = LnA + a_2LnIr + (a_5\text{-}1)LnH \qquad (5.15)$$

$$Ln(Q/H) = LnA + a_3LnRD + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.16)$$

$$Ln(Q/H) = LnA + a_3LnRD + (a_5\text{-}1)LnH \qquad (5.17)$$

$$Ln(Q/H) = LnA + a_4LnKRD + (a_5\text{-}1)LnH \qquad (5.18)$$

where Q/H is rice productivity (kgs/rai), F is chemical fertiliser use (Kilogram) , Ir is the irrigated area, RD is rice R&D expenditure in real terms (Baht), KRD is the stock of R&D knowledge[16] in real term (Baht), A is a constant factor, a_1 through to a_5 are rice yield elasticities of fertilizer, irrigation, R&D expenditure, R&D knowledge stock, and hectarage respectively.

Moreover, to investigate the relationship among all explanatory variables in the yield function (equation 5.4), the fertiliser response function is assumed to form as irrigated area, current R&D expenditure, and R&D knowledge stock, and hectarage are all independent variables. All the variables have been expressed in logarithms as follows:

$$LnF = LnA + a_6LnIr + a_7LnRD + a_8LnKRD + a_9LnH \tag{5.19}$$

$$LnF = LnA + a_6LnIr + a_7LnRD + a_8LnKRD \tag{5.20}$$

A is a constant term; a_6 to a_9 are chemical fertilizer elsticities of irrigated area, current R&D expenditure, R&D knowledge stock, and hectarage respectively.

In this study, time series data has been collected from different sources to make it suitable for econometric analysis. The average annual data of macro-level or aggregate level is used. The set of annual data for paddy production and harvested areas of paddy available date back to 1950. The annual data of R&D expenditures in rice was available from 1950-1998. Data on fertilizer use in rice fields, and

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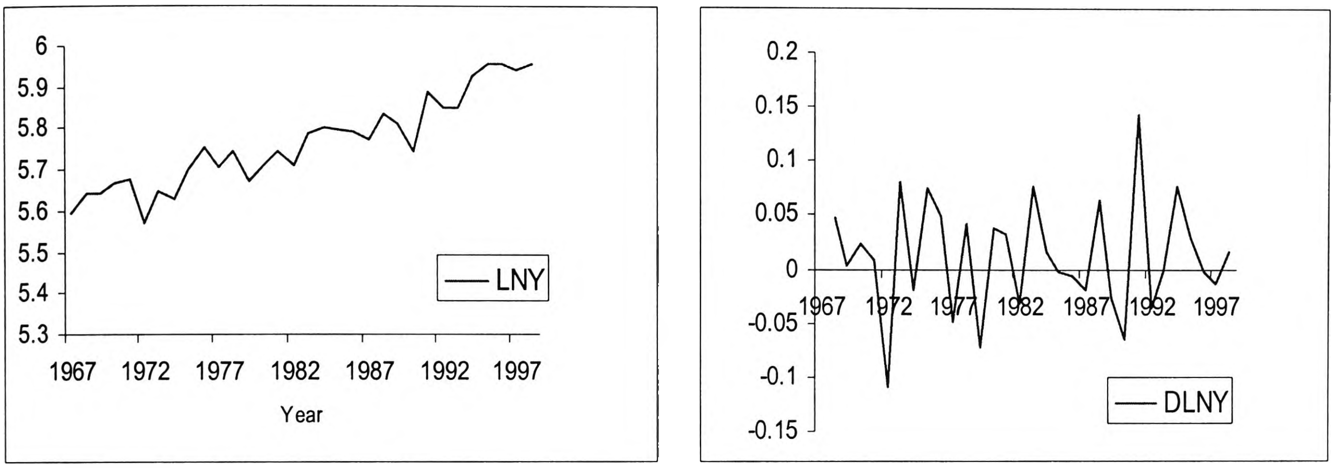
[16] The stock of R&D knowledge or the existing body of knowledge was firstly included as a separable variable in a production function for industrial sector study by Griliches and Lichtenberg, (1984). Huffman and Evenson (1992) included this variable in agricultural productivity function. Setboonsarng and Evenson (1991), and Pochanukul (1992) constructed the accumulative research expenditures of the specific forms as a single variable for research capital into their models. Alston et al (1996 and 1998b) proposed the stock of knowledge in his productivity model compared to agricultural R&D expenditure with arbitrary restrictions on the length and shape of the R&D lag profile.

irrigated area were available from 1967-1998. A detailed description of the data and sources is given in Appendix B.

The relationship between agricultural R&D activity and productivity is one of the most important and enduring issues concerning agricultural production. From the preliminary investigation in Chapter 3, the evidence suggests that the trends of rice productivity, fertilizer use, irrigated area, and R&D seem to coincide. All time-series data shows a strong upward trend that may show some spurious results resulting from non-stationary time series. To avoid this problem, the cointegration technique is used to determine the feasible long-run relationships among the time-series variables involved. Before the cointegration approach is employed, the unit root test will be applied to investigate the properties of all time-series data involved.

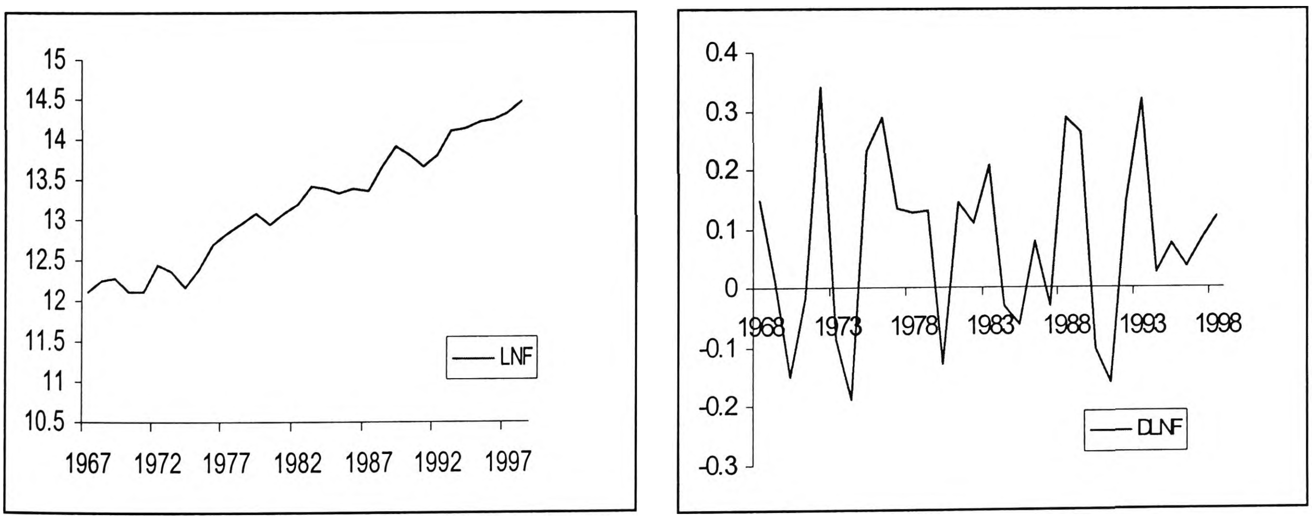
However, before the unit root test is conducted, all major time-series variables are plotted in order to investigate their characteristics. Figures 5.1 to 5.9 show the characteristics of time series data in logarithmic form both at the level and the first to third difference. The logarithms of time-series data at level show random fluctuations in an upward trend. They seem to be non-stationary in levels, meanwhile the logarithms of time-series data at first difference for rice yield, chemical fertilizer, and harvested area, exhibit random fluctuations around zero or are stationary at the first difference, I(1). While the time series data for irrigated area and R&D expenditure are stationary at the second difference, I(2), the time series data for R&D knowledge stock are stationary at the third difference, I(3). These figures show that the time series seem to be stationary at various differences. However, graphical patterns are not always so clear cut as those just examined. Thus, in order to use econometric method, the unit root test will be applied to investigate the properties of the time series.

Figure 5.1 Rice Yields in Logarithm of Level and First Difference, 1967-1998



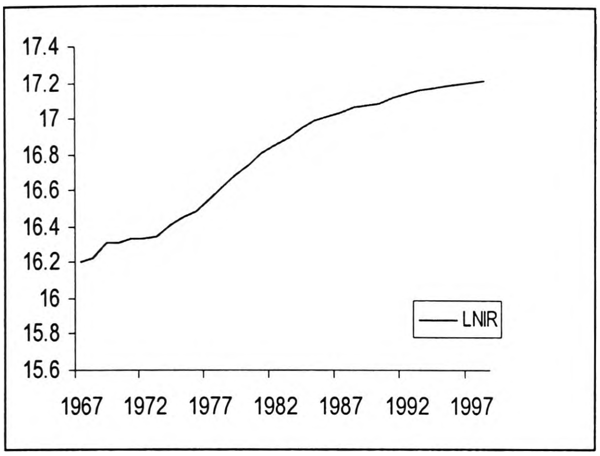
Source: Taking logarithm from data in Table A.9 (Appendix A)

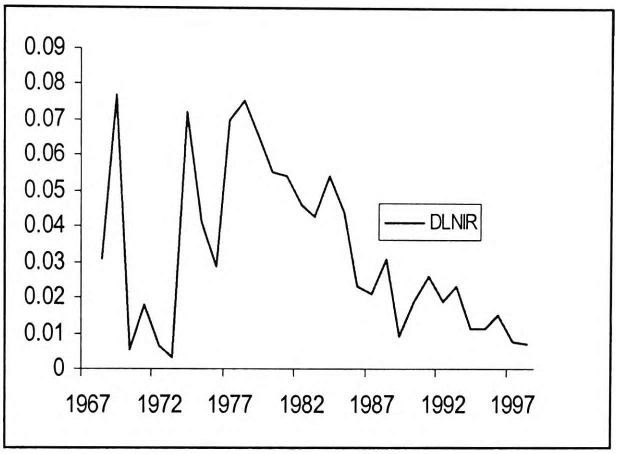
Figure 5.2 Fertilizer Usage in Logarithm of Level and First Difference, 1967-1998



Source: Taking logarithm from data in Table A.9 (Appendix A)

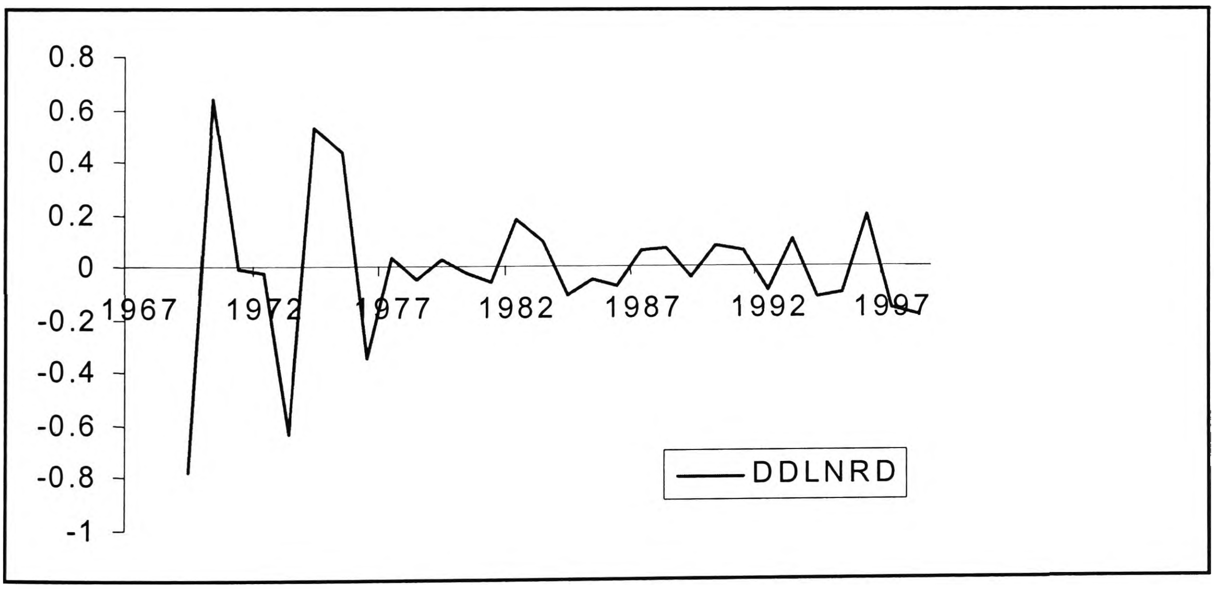
Figure 5.3 Irrigated Area in Logarithm of Level and First Difference, 1967-1998





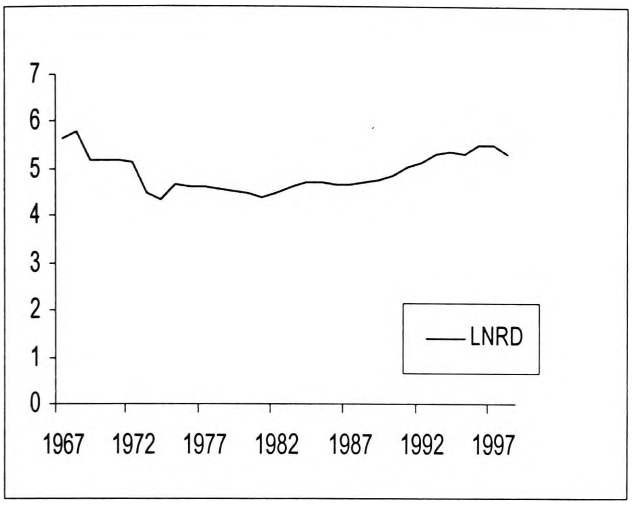
Source: Taking logarithm from data in Table A.9 (Appendix A)

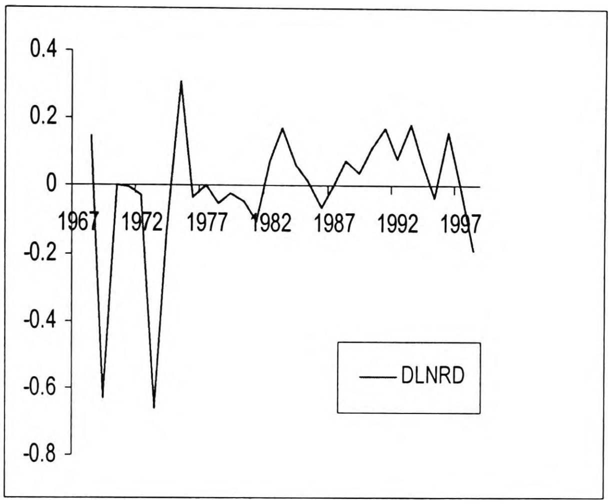
Figure 5.4 Irrigated Area in Logarithm of Second Difference, 1967-1998



Source: Taking logarithm from data in Table A.9 (Appendix A)

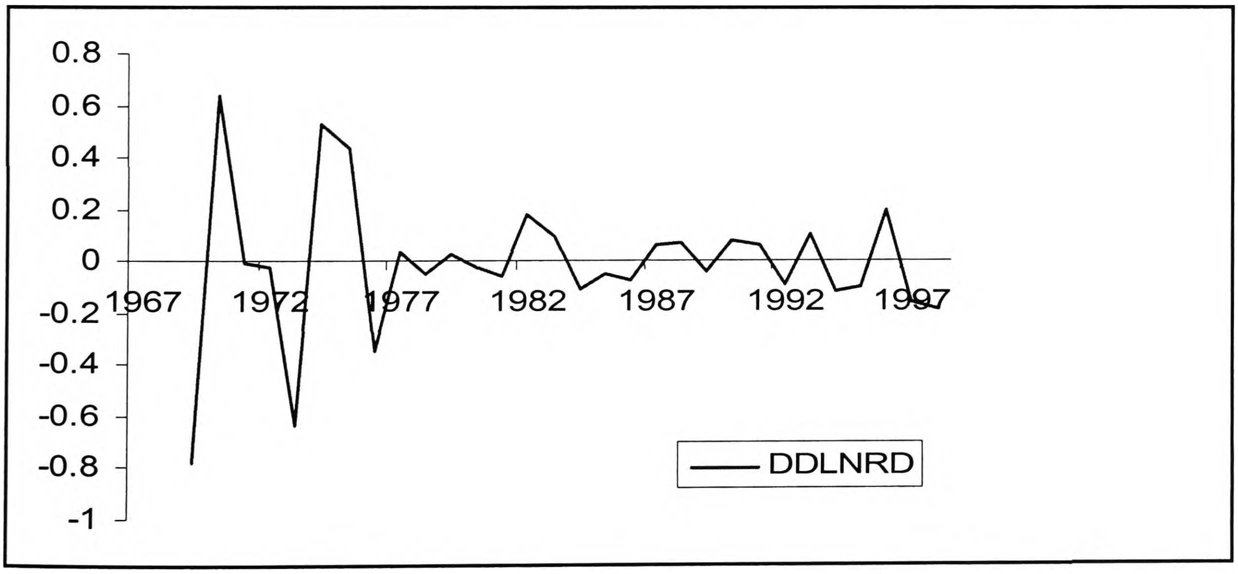
Figure 5.5 R&D Expenditure in Logarithm of Level and First Difference, 1967-1998





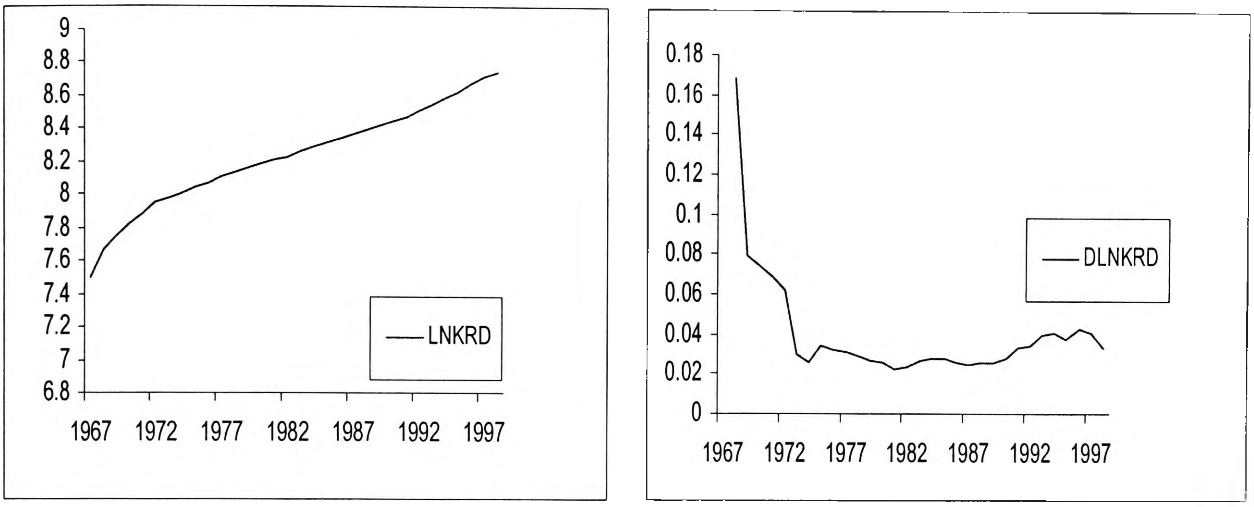
Source: Taking logarithm from data in Table A.9 (Appendix A)

Figure 5.6 R&D Expenditure in Logarithm of Second Difference, 1967-1998



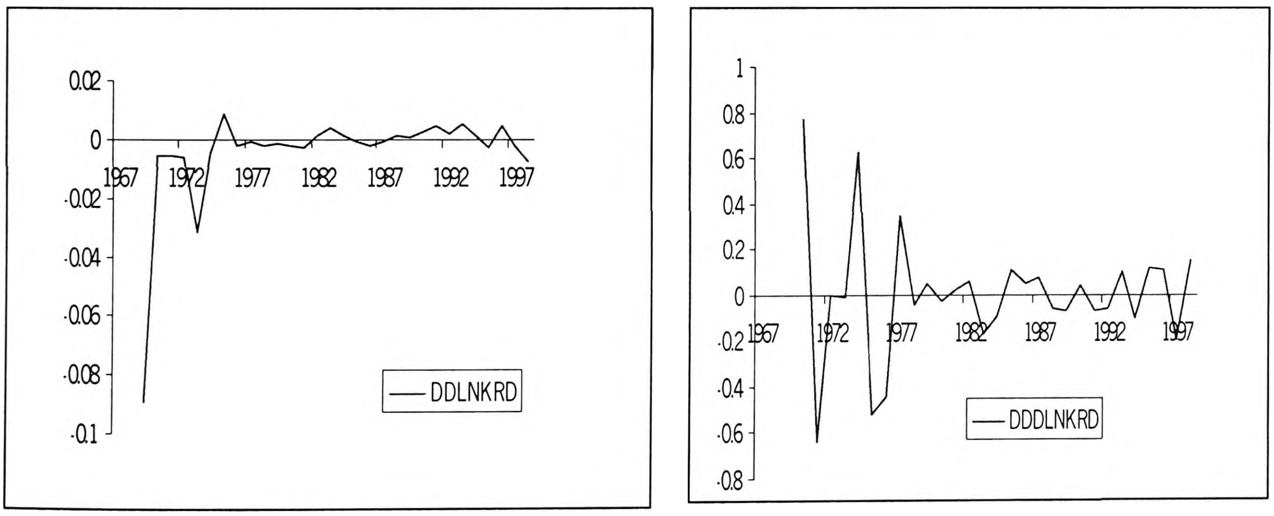
Source: Taking logarithm from data in Table A.9 (Appendix A)

Figure 5.7 R&D Knowledge Stock in Logarithm of Level and First Difference, 1967-1998



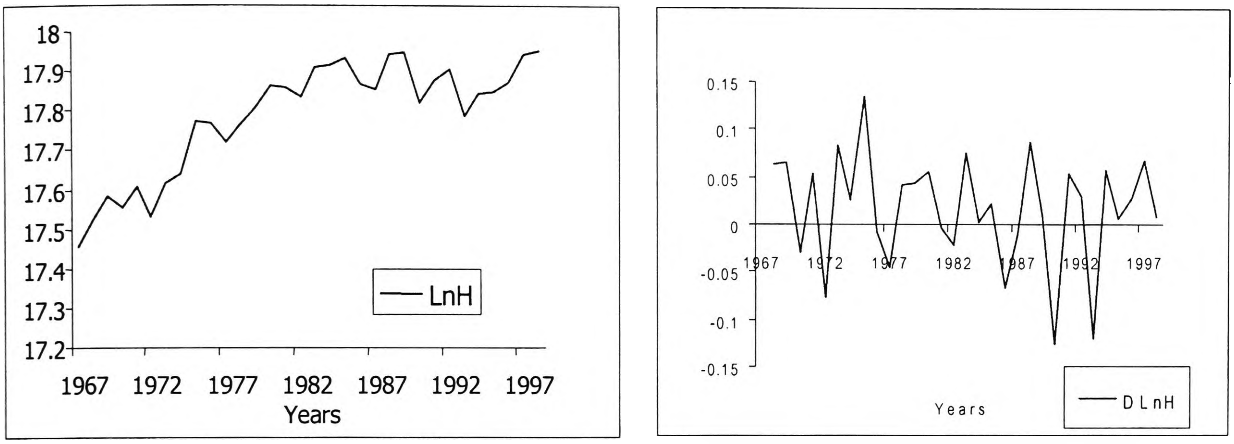
Source: Taking logarithm from data in Table A.9 (Appendix A)

Figure 5.8 R&D Knowledge Stock in Logarithm of Second and Third Difference, 1967-1998



Source: Taking logarithm from data in Table A.9 (Appendix A)

Figure 5.9 Harvested Rice Area of Level and First Difference, 1967-1998



Source: Taking logarithm from data in Table A.9 (Appendix A)

5.3 Unit Root Test

The time series variables in equation (5.4) to (5.20) are considered whether they are stationary or not. As time series data is characterized as being non-stationary, regression analysis will yield inappropriate classical statistical values. Despite obtaining high R^2 values and t-statistics, and a very low Durbin-Watson statistic, time series results often lead to spurious regression results or point to untrue economic relationships between the variables. The Ordinary Least Squares (OLS) method would not yield a consistent parameter estimator due to the time-series data exhibiting strong time trends. Moreover, regression using time series data to investigate economic relationships often gives highly autocorrelated residuals and results in biased hypothesis tests (Granger & Newbold, 1974).

Dickey and Fuller (1979) considered three possible testing equations, known as DF tests which may be employed to examine unit root tests:

$$\Delta y_t = \delta y_{t-1} + \varepsilon_t \tag{5.21}$$

$$\Delta y_t = \beta_1 + \delta y_{t-1} + \varepsilon_t \tag{5.22}$$

$$\Delta y_t = \beta_1 + \beta_2 t + \delta y_{t-1} + \varepsilon_t \tag{5.23}$$

where y_t is the time series to be tested for a unit root, t is a deterministic time trend, and ε_t is the disturbance term satisfying the classical assumptions, known as white noise. The null hypothesis of this test is that $\delta = 0$. If ρ is close to unity, the coefficient of y_{t-1}, say $\delta = (1 - \rho)$, will not be significantly different from zero. If the unit root does not exist, y_t is said to be stationary in the levels {denoted I(0)}. If the unit root exists, but if after differentiation the series are stationary, y_t is said to be stationary in difference {denoted I(1)}. The critical t-value for the tests is called Dicky-Fuller statistic. The specific critical values have been tabulated by Dicky and Fuller based on Monte Carlo simulations.

However, the DF test has a weakness in that it does not account for possible autocorrelation in the disturbance term ε_t, resulting in inefficient OLS estimates. In order to solve this problem, each of the equations (5.21) to (5.23) can be modified by adding lags of the difference of y_t known as the augmented Dicky-Fuller (ADF) test:

$$\Delta y_t = \delta y_{t-1} + \alpha_i \sum_{i=1}^{m} \Delta y_{t-i} + \varepsilon t \tag{5.24}$$

$$\Delta y_t = \beta_1 + \delta y_{t-1} + \alpha_i \sum_{i=1}^{m} \Delta y_{t-i} + \varepsilon t \tag{5.25}$$

$$\Delta y_t = \beta_1 + \beta_1 t + \delta y_{t-1} + \alpha_i \sum_{i=1}^{m} \Delta y_{t-i} + \varepsilon t \tag{5.26}$$

where m is the number of order autoregressive process. In this case, the null hypothesis remains $\delta = 0$, that is, a unit root exists in time series variable y (nonstationary). To select the order of the ADF regression, the Akaike Information Criterion (AIC) and the Schwarz Bayesian Critirion (SBC) are used.

As the aim of this study is to provide evidence for appropriate policy formulation, it is necessary to test the time-series data properties before investigating the long-run relationship among relevant variables. The tests are conducted on all the available time-series data over 32 years (1967-1998) on agricultural rice yield and inputs per unit of cultivated area which may be a random walk with a drift and or a trend-stationary process. The Augmented Dicky-Fuller (ADF) test is chosen as this method is widely used to test for the presence of unit roots in time-series variables. The test is applied to the variables in their logarithmic form.

Using the Microfit 4.0 program, the results of applying the ADF procedure to the data for the natural logarithms of all variables: rice productivity (Q/H), chemical fertilizer used in paddy rice (F), irrigated area (Ir), deflated rice R&D expenditure (RD), R&D knowledge stock (KRD), and rice harvest area (H) over the period 1967 to 1998 is reported in Table 5.1. The results of the ADF unit root tests with trend indicate that all time series data are non-stationary at all levels.

After the initial differencing, time-series variables for rice yield, chemical fertilizer and harvested area reject the null hypothesis of non-stationarity at the 5 percent level, while the time series data for irrigated area, R&D expenditure, and R&D knowledge stock do not reject the null hypothesis at the 5 percent level. However, when the second differentiation is used, the time series data variables for irrigated area and R&D expenditure reject the null hypothesis at the 5 percent level, but the null hypothesis is not rejected at the 5 percent level by R&D knowledge stock. After third differencing, the time series variables for R&D knowledge stock are stationary at the 5 percent level. According to the ADF unit root test, all time-series data are significantly non-stationary at levels, and stationary at differences. As such some variables require differentiated properties before all time-series data in equations (5.4) to (5.20) can be used to investigate the existence of long-term relationships using the cointegration approach.

Table 5.1 Stationary Tests of Rice Yield and Input Variables

	Ho: Non-stationary at levels	Ho: Non-stationary in Differences		
Variable	ADF	ADF First Difference	ADF Second Difference	ADF Third Difference
LnQ/H	-2.78(1)	-4.42(5)*	-	-
LnF	2.63(5)	-5.37(1)*	-	-
LnIr	-1.49(3)	-0.82(3)	-6.79(1)*	-
LnRD	-1.03(3)	-2.77(1)	-4.28(1)*	-
LnKRD	-2.62(3)	-1.49(1)	2.43(1)	-4.34(6)*
LnH	-2.66(2)	-6.39(1)*	-	-

Sources: Computed from the data in Table A.7, A.9 and A.10 (Appendix A) by using Microfit 4.0 with ADF.

Notes: 1) The order of ADF tests are shown in the brackets.
2) The critical value used at 5% without trend is -3.00 and with trend is -3.61.
3) * is significant at 5% level

5.4 Cointegration Test

The classical methods of estimation of regression are based on the assumption that the mean of error terms is zero and the variance is constant. This indicates that the mean and variance of the variables are independent of time. However, the concept of the unit root shows that these assumptions are not satisfied by a large number of macroeconomics time series. Means and variances of variables that change over time are known as non-stationary or unit root time-series. The unit root test has also shown that using the ordinary least squares (OLS) to estimate relationships with unit root variables leads to misleading inferences, known as the spurious regression problem. A spurious regression is realized when the estimated regression obtains a high R^2, high t-value, but a low value for the Durbin Watson test (DW).

Because of this problem, the cointegration approach has been considered as an implication for unit roots time series. This approach is viewed as a technique to estimate the equilibrium or long-term parameters in a relationship with unit root variables. However, integrating unit roots and cointegration has important implications for the specification and estimations of economic models such as the aggregate production function over a long period.

Cointegration is a technique used to estimate the equilibrium or long-term parameters in a relationship, even if the variables are non-stationary. When y and x are cointegrated, it means that the two variables share a long-term relationship. If two variables, y and x, have the same order of integration, I(d), and a linear combination of the two ($Z_t = Yt - \rho Xt$) is stationary, then y and x are cointegrated, and ρ is called the cointegrating parameter.

If non-stationary time-series data is used to estimate regressions, spurious results may be obtained generating misleading statistical economic information. One way to solve this problem is to take the differences (first order or higher) of all non-stationary variables used in a model until they become a stationary time series. This method may result in the loss of a valuable long-term relationship between variables. However, if non-stationary variables are cointegrated, a long-term relationship exists. The regression on the levels of the variables is meaningful and it does not lose any valuable long-run information from the relationship.

However, all time series data in this study do not have the same properties. In the case of single equation investigations for multivariate cases, each time series variable in the model will need to have the same order of integration. In this case, the time series data of rice yield (Q/H =Y), chemical fertilizer (F), and harvested area (H) are stationary at first order, I(1), while time series data of irrigation area (Ir), R&D expenditure (RD) are second order, I(2), and rice R&D knowledge stock (KRD) is third order, I(3). Thus, the time series data will need to be converted to the same property before any investigation concerning long-term relationships can take place. Ir and RD will need to be differentiated once, and twice for KRD, so that all variables in the model have the same time series properties.

There are three methods to test whether the time series variables in the model are cointegrated: the Engle and Granger two-step, the Johansen maximum likelihood method (ML), and the Stock-Watson procedures. Currently, the Johansen ML method is widely used and seems to yield more satisfactory results (Rao, 1994:7). This method is chosen because there is evidence that it performs the multivariate method better than the univariate method (Gonzalo, 1994)). Moreover, testing cointegration in a vector autoregression (VAR) model[17] is often regarded as superior

[17] In a vector autoregression (VAR) model, each variable is allowed to affect every other variable in the system with lag (Bessler, 1984)

to the Engel-Granger single equation method. The statistical properties of the Johansen approach are generally better and the power of the cointegration test is higher(Charemza and Deadman, 1993:201). The Johanson approach derives maximum-likelihood estimates of the cointegrating vectors and provides a likelihood ratio test to determine whether cointegrating vectors exist for a VAR system. This approach is robust because it considers all possible cointegrating vectors in the system.

The Johansen's model-based procedure (Johansen, 1988, 1991, and 1992; Johansen and Juselius, 1990) is based upon an assumption of multivariate normality. This procedure is considered when more than two time-series are being used, and a result, more than one stable linear combination can exist. We assume that the multivariate AR(1) representation is as follows:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \ldots.. + A_p Y_{t-p} + \varepsilon_t \qquad (5.27)$$

where Y_t ($n \times 1$ vector) is Z_t minus μ, where Z_t is a vector of economic time series, and μ is the vector of the means of Z, A_1, A_2, …, A_p are $n \times n$ matrix, and ε_t is a vector of error terms that are stationary around zero, i.e. $E(\varepsilon_t) = 0$ and $E(\varepsilon_t \varepsilon'_t) = \Omega$ for all t.

Equation (6.25) can be reparameterised as either

$$\Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \Gamma_2 \Delta Y_{t-2} + \ldots.. + \Gamma_{p-1} \Delta Y_{t-p+1} + \psi Y_{t-p} + \varepsilon_t \qquad (5.28)$$

or

$$\Delta Y_t = \Theta_1 \Delta Y_{t-1} + \Theta_2 \Delta Y_{t-2} + \ldots.. + \Theta_{p-1} \Delta Y_{t-p+1} + \psi Y_{t-1} + \varepsilon_t \qquad (5.29)$$

If the matrix $\psi = (I - A_1 - A_2 - \dots - A_p)$ is full rank, then any linear combination of Y_t will be stationary. If ψ is a matrix of zeros, any linear combination of Y_t will be a unit root process or non-stationary. Testing for cointegration determines the rank of ψ by testing whether the eigenvalue of hat-ψ are significantly different from zero.

There are two test statistics for the number of cointegration vector: the trace and maximum eigenvalue statistics. For the trace test, the null hypothesis is that the number of cointegrating vectors is less than or equal to r, where r is the number of linearly independent and stationary linear combinations of Y_t that can be found. In each case, the null hypothesis is tested against the general alternative. The testing involves determining whether there is no cointegration (r=0) versus, at most, 1 such relation. If this is rejected, a further test determines whether there is, at most, one cointegration relation versus two, and so on. Finally, the null hypothesis of, at most, r=m-1 cointegration relationships is rejected, it finds that the Yt vector series is stationary. The trace test statistic proposed in Johansen (1988) is as follows:

$$\text{Trace} = -n \sum_{i=r+1}^{m} \log(1 - \lambda_i) \tag{5.30}$$

For the maximum eigenvalue, the null hypothesis r=0 is tested against the alternative that r=1, r=1 against the alternative r=2, and so on. The critical values for these tests are tabulated by Johansen (1995) and Boswijk (1998). The maximum eigenvalues statistic is:

$$\lambda_{max} = -n \log(1 - \lambda_r), \tag{5.31}$$

which can be used to test the null hypothesis of r-1 against r cointegration relations.

Furthermore, the Johansen procedure can evaluate the validity of a unit coefficient for a variable (say x, determined as an explanatory variable) in a equilibrium relationship that is normalized to the equation with respect to one variable so that another variable (say y, determined as a dependency variable) appears with a coefficient of one (Rao, 1994). Sometimes this is taken to mean that y is the dependent variable in the equation. Thus, the coefficient of x is interpreted as the coefficient of x with respect to y.

As the result of the unit root test, all variables in equation (5.4) to (5.20) are integrated to the order of one, two, and three. Theoretically, every variable in the model specification will need to have the same order of integration. The next step is to test whether all time series in the equations (6.4) to (6.20) are cointegrated, by using the multivariate cointegration method suggested by Johansen (1988) and Johansen & Juselius (1990).

There are three steps in applying the cointegration approach with Johansen's procedure to test statistics. Firstly, an appropriate lag length in unconstrained vector autoregression (VAR) is determined. Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC) are used as criteria to select the optimal lag length for the VAR. Secondly, the residuals of the individual equations in the VAR are checked for possible serial correlation and heteroskasdasticity. Thirdly, testing for cointegration is undertaken using the maximum trace and maximum eigenvalue statistics. In this step, feasible cointegrating vectors are tested to determine whether they exist. In other words the time series variables are cointegrated if the two statistics are found to reject the null hypothesis of no cointegration.

With this procedure it is important to determine an appropriate lag length to use in the VAR model. The AIC and the SBC select order one for equation (6.11), (5.18) and (5.19), order two for equation (5.17) and (5.20), order three for equation (5.4), and order four for equation (5.5), (5.6), (5.10), and (5.12). Order five is selected for equation (5.7), (5.8), (5.9), (5.13), (5.14), and (5.16), and order six for equation (5.15). The results of selecting the order of the VAR indicate the adoption of the above orders as the optimal number of lags for the cointegrating regression. To confirm the order of lag length in terms of residual whiteness, the Largrange Multiplier (LM) test and F-test are applied to detect serial correlation and heteroskadasticity. The test results show no evidence of residual serial correlation and heteroskasdasticity both in either LM or F test. Thus, the selected VAR models are free from serial correlation and heteroskasdasticity problems, and therefore, the above orders have been utilized.

Table 5.2 reports the results of the two test statistics as calculated using the Microfit 4.0 program (Pesaran and Pesaran, 1996). The LR test, based upon the maximal eigenvalues and the trace test give similar results. At a 95 percent confidence level, the test based upon the maximal eigenvalue indicates that there is at least one cointegrating vector, and the results based upon the trace test suggest that there are at most one cointegrating vector for equations (5.11), (5.17), (5.18) and (5.20).

For equations (5.4), (5.5), (5.8), (5.16) and (5.19), the LR test based upon maximal eigenvalues indicates that there are two cointegrating vectors (r=0,1) against the alternative of two cointegrating vectors (r =1, 2), the test statistic is greater than the 95 percent critical value, rejecting the null hypothesis and indicating that there are at least two cointegrating vectors. Conversely, the LR test, based upon the trace of the stochastic matrix, indicates that there are, at most, four, two, two, three and three cointegrating vectors respectively.

The maximal eigenvalue test for equations (5.6), (5.7), (5.9), (5.13), (5.14), and (5.15) indicates that there are three cointegrating vectors, while the trac test suggests that there are at most five for equation (5.6) and three for the remaining equations. For equations (5.10) and (5.12), the test, based upon maximal eigenvalues, indicates that there are four cointegrating vectors, and the test based upon trace values suggests that there are at most four cointegrating vectors.

Thus, the time-series data appears to support the notion that chemical fertilizers, irrigated area, R&D expenditure, R&D knowledge stock, and hectarage seem to have played important roles in rice yields in Thailand from 1967 to 1998. The null hypothesis states that there is no cointegration to be rejected at the 5 percent significant level, supporting the non-spurious regression with in the VAR models.

In conclusion, all of the time series variables in the models are cointegrated. This means a long-run relationships exists between rice yield, chemical fertilizers, irrigated area, R&D expenditure, R&D knowledge stock, and hectarage, and the regressions on levels of the variables are meaningful (not spurious). It can be estimated using OLS to find the long-run response of rice yield to a change in independent variables.

Table 5.2 Results of Johansen Cointegration Test for Thailand, 1967-1998

Equations	Null	Eigenvalue Test	95% Critical Value	Trace Test	95% Critical Value
(5.4) LnQ/H LnF LnIr LnRD LnKRD Ln H (VAR=3)					
	r = 0	97.81	40.53	238.64	102.56
	r ≤ 1	76.78	34.40	140.82	75.98
	r ≤ 2	25.15	28.27	64.04	53.48
	r ≤ 3	19.60	22.04	38.90	34.87
	r ≤ 4	15.23	15.87	19.29	20.18
	r ≤ 5	4.06	9.16	4.06	9.16
(5.5) LnQ/H LnF LnIr LnRD Ln H (VAR = 4)					
	r = 0	179.78	34.40	296.99	75.98
	r ≤ 1	87.25	28.27	117.21	53.48
	r ≤ 2	12.82	22.04	29.97	34.87
	r ≤ 3	11.71	15.87	17.14	20.18
	r ≤ 4	5.44	9.16	5.44	9.16
(5.6) LnQ/H LnF LnIr LnKRD Ln H (VAR = 4)					
	r = 0	270.62	34.40	402.93	75.98
	r ≤ 1	83.20	28.27	132.31	53.48
	r ≤ 2	23.14	22.04	49.12	34.87
	r ≤ 3	15.61	15.87	25.97	20.18
	r ≤ 4	10.36	9.16	10.36	9.16
(5.7) LnQ/H LnF LnIr Ln H (VAR = 5)					
	r = 0	65.40	28.27	139.45	53.48
	r ≤ 1	36.44	22.04	74.05	34.87
	r ≤ 2	32.45	15.87	37.61	20.18
	r ≤ 3	5.17	9.16	5.17	9.16

Sources: Estimated from the data in Table A.6, A.7 and A.9 (Appendix A) by using Microfit 4.0 with Cointegration of Johansen ML approach (Pesaran and Pesaran, 1996:291-297)

Note: r denotes the number of cointegrating factors.

Table 5.2 Results of Johansen Cointegration Test for Thailand, 1967-1998 (continued)

Equations	Null	Eigenvalue Test	95% Critical Value	Trace Test	95% Critical Value
(5.8) LnQ/H LnF LnRD Ln H (VAR= 5)					
	r = 0	91.25	28.27	138.92	53.48
	r ≤ 1	30.88	22.04	47.67	34.87
	r ≤ 2	10.66	15.87	16.79	20.18
	r ≤ 3	6.13	9.16	6.13	9.16
(5.9) LnQ/H LnF LnKRD Ln H (VAR = 5)					
	r = 0	98.93	28.27	204.74	53.48
	r ≤ 1	76.83	22.04	105.81	34.87
	r ≤ 2	26.04	15.87	28.99	20.18
	r ≤ 3	2.94	9.16	2.94	9.16
(5.10) LnQ/H LnF LnRD LnKRD Ln H (VAR = 4)					
	r = 0	178.36	34.40	369.36	71.81
	r ≤ 1	125.82	28.27	190.99	53.48
	r ≤ 2	33.68	22.04	65.18	34.87
	r ≤ 3	24.22	15.87	31.50	20.18
	r ≤ 4	7.27	9.16	7.27	9.16
(5.11) LnQ/H LnF Ln H (VAR = 1)					
	r ≤ 1	25.95	22.04	40.37	34.87
	r ≤ 2	8.51	15.87	14.42	20.18
	r ≤ 3	5.91	9.16	5.90	9.16

Sources: Estimated from the data in TableA.6, A.7 and A.9 (Appendix A) by using Microfit 4.0 with Cointegration of Johansen ML approach (Pesaran and Pesaran, 1996:291-297)

Note: r denotes the number of cointegrating factors.

Table 5.2 Results of Johansen Cointegration Test for Thailand, 1967-1998 (continued)

Cointegrating Regression	Null	Eigenvalue Test	95% Critical Value	Trace Test	95% Critical Value
(5.12) LnQ/H LnIr LnRD LnKRD LnH (VAR = 4)					
	r = 0	183.41	34.40	377.16	75.98
	r ≤ 1	108.96	28.27	193.75	53.48
	r ≤ 2	46.14	22.04	84.79	34.87
	r ≤ 3	31.83	15.87	38.65	20.18
	r ≤ 4	6.82	9.16	6.82	9.16
(5.13) LnQ/H LnIr LnRD Ln H (VAR = 5)					
	r = 0	67.42	28.27	156.73	53.48
	r ≤ 1	48.57	22.04	89.31	34.87
	r ≤ 2	32.58	15.87	40.74	20.18
	r ≤ 3	8.16	9.16	8.16	9.16
(5.14) LnQ/H LnIr LnKRD Ln H (VAR = 5)					
	r = 0	112.62	28.27	199.63	53.48
	r ≤ 1	62.43	22.04	87.03	34.87
	r ≤ 2	19.40	15.87	24.60	20.18
	r ≤ 3	5.20	9.16	5.20	9.16
(5.15) LnQ/H LnIr LnH (VAR = 6)					
	r = 0	40.44	22.04	70.61	34.87
	r ≤ 1	19.89	15.87	30.18	20.18
	r ≤ 2	10.28	9.16	10.29	9.16

Sources: Estimated from the data in TableA.6, A.7 and A.9 (Appendix A) by using Microfit 4.0 with Cointegration of Johansen ML approach (Pesaran and Pesaran, 1996:291-297)

Note: r denotes the number of cointegrating factors.

Table 5.2 Results of Johansen Cointegration Test for Thailand, 1967-1998 (continued)

Cointegrating Regression	Null	Eigenvalue Test	95% Critical Value	Trace Test	95% Critical Value
(5.16) LnQ/H LnRD LnKRD Ln H (VAR = 5)					
	r = 0	63.02	28.27	113.75	53.48
	r ≤ 1	30.15	22.04	50.73	34.87
	r ≤ 2	12.73	15.87	20.58	20.18
	r ≤ 3	7.85	9.16	7.85	9.16
(5.17) LnQ/H LnRD Ln H (VAR = 2)					
	r = 0	35.54	22.04	42.94	34.87
	r ≤ 1	4.44	15.87	7.40	20.18
	r ≤ 2	2.96	9.16	2.96	9.16
(5.18) LnQ/H LnKRD Ln H (VAR=1)					
	r = 0	64.52	22.04	73.73	34.87
	r ≤ 1	6.94	15.87	9.21	20.18
	r ≤ 2	2.27	9.16	2.27	9.16
(5.19) LnF LnIr LnRD LnKRD Ln H (VAR=1)					
	r = 0	146.34	28.27	195.75	53.48
	r ≤ 1	28.30	22.04	49.41	34.87
	r ≤ 2	13.34	15.87	21.11	20.18
	r ≤ 3	7.77	9.16	7.77	9.16
(5.20) LnF LnIr LnRD LnKRD (VAR=2)					
	r = 0	37.07	34.40	30.37	75.98
	r ≤ 1	27.23	28.27	53.29	53.48
	r ≤ 2	14.45	22.04	26.07	34.87
	r ≤ 3	6.55	15.87	11.61	20.18
	r ≤ 4	5.06	9.16	5.06	9.16

Sources: Estimated from the data in TableA.6, A.7 and A.9 (Appendix A) by using Microfit 4.0 with Cointegration of Johansen ML approach (Pesaran and Pesaran, 1996:291-297)

Notes: r denotes the number of cointegrating factors.

5.5 Model Estimation

All rice yield equations and expected explanatory variables are cointegrated, measuring all of the time series data share long-term relationships. The relationships do not appear to be spurious, and as a result the regression equation can be estimated using OLS to determine the long-term response of rice yields to a change in the explanatory variables.

To evaluate the compatibility of the estimated equations, two categories of criteria are used. The first is the implications of production economic theories on relevant factors in the relationship. Such implications are judged from the theoretically expected signs of parameters and the theoretically expected magnitudes of the coefficients of the estimated models. The second criterion is a set of statistical criteria such as the adjusted coefficient of determination (R-bar square), the t-statistic of the estimated coefficients, and the Durbin-Watson statistic. The results of rice yield equations estimation are shown in Table 5.3. The estimated models are detailed in Appendix F.

The models represented by the 15 equations which have been transformed into a yield function based on the Cobb-Douglas production function. The general model includes five factors namely chemical fertilizers, irrigated area, R&D expenditure, R&D knowledge stock, and harvested area. Yield elasticities estimated from data for the period 1967-1998 are summarised in Table 5.3. In addition, Appendix F presents the results from the 15 equations.

Unsurprisingly, current R&D expenditures, R&D knowledge stock, and hectarage have a highly positive significant effect on rice yields in all equations involving all three factors (equations (5.4), (5.10), (5.12), and (5.16)). This confirms the hypothesis that R&D activities in rice are important factors indetermining an increase in rice yield. The equations with the largest concentration of significant coefficients in Table 5.3 are equation (5.4), (5.8), (5.10), (5.12), (5.13), and (5.16). All of coefficients in these equations are statistically significant. The R-bar squared calculations are high, ranging from 0.87 to 0.91, and the D.W-statistics are satisfied.

Equation (5.8) shows the relationship between rice yield, chemical fertilizer use, current R&D expenditure, and harvested area to be significantly positive with feasible magnitudes. If chemical fertilizer use increases by 1 percent while holding all other factors constant, rice yield will rise by 0.06 percent. Similarly, if real R&D expenditures increase by 1 percent, holding the other factors constant, rice yield will rise by 0.09 percent. If harvested area increases by 1 percent, again under the same conditions, rice yield will rise by 0.40 percent.

Equation (5.13) represents the relationship between rice yield, irrigation area, current R&D expenditure, and harvested area with statistically positive results and feasible magnitudes. If the irrigation area increases by 1 percent holding all other factors constant, rice yield will rise by 0.13 percent. Similarly, if real R&D expenditures increase by 1 percent, holding the other factors constant, rice yield will rise by 0.11 percent. If the harvested area increases by 1 percent holding other factors constant, rice yield will rise by 0.40 percent.

Equations (5.4), (5.8), (5.10), (5.12), (5.13), and (5.16) indicate that chemical fertilizer, current R&D and hectarage are complementary factors capable of increasing rice yield. Similarly, irrigation, current R&D, and hectarage are also complementary factors for rice production. Irrigation is approximately twice as effective as fertilizer for increasing rice yield.

The important role of R&D activity in increasing rice yield is shown in equation (5.16). Both current R&D expenditure and R&D knowledge stock respond to rice yield with high statistical significance and expected results. If current R&D expenditure increases by 1 percent, holding all other factors constant, rice yield will increase by 0.10 percent. Similarly, if R&D knowledge stock increases by 1 percent holding other factors constant, rice yield will rise by 0.20 percent. This indicates that R&D knowledge stock is a more important determinant of rice yield than current R&D expenditure.

It is also important to note that the significant elasticities of rice yield with respect to current R&D expenditures (a_3) range from 0.09 to 0.14, indicating that if current R&D expenditure increases by 1 percent, rice from yield will rise from 0.09 to 0.14 percent. The significant elasticities of rice yield with respect to R&D knowledge stock (a_4) range from 0.20 to 0.33, indicating if R&D knowledge stock increases by 1 percent, rice yield will rise from 0.20 to 0.33 percent. This data indicates that the R&D knowledge stock is a more important determinant of rice yield than current R&D expenditure around twice as effective as current R&D expenditure for increasing rice yield. Similarly, the significant elasticities of rice yield with respect to harvested area ($a_5 - 1$) range from 0.31 to 0.71. The effect of harvested area on rice yield is rather large. This indicates that land expansion is the most important determinant of rice yield. If hectarage increases by 1 percent, rice yield will rise from 0.31 to 0.71 percent. This positive partial elasticity of rice yield to harvested area can be interpreted as the result of past expansion of rice land (fertility area), derived from the area of a massive encroachment of forest area and some development programs of the Thai government in the 1970, and in the carly 1980, is an important factor to increase rice yield (Isvilanonda and Poapongsakorn, 1995:2). Moreover, TDRI (1988) indicated that fertilizer application had undoubtedly increased, partly to increase land fertility.

Equations (5.8), (5.13), and (5.16), which relate rice yield to fertilizer usage, irrigation, current R&D expenditure, and R&D knowledge stock, and harvested area of rice, produce feasible results with the expected effects on each variable and provide a significant set of statistical criteria. These three equations show no evidence of heteroskedasticity or serial correlation problems (both LM and F versions (Appendix C)). However, the multicollinearity problem remains (Appendix D). Although this problem makes the corresponding coefficients difficult to interpret individually, the estimated coefficients are still acceptable. One method to eliminate this problem, the total factor productivity (TFP) index should be applied instead of partial productivity (rice yield). Hence, these equations are chosen for calculating the elasticity of rice yield with respect to inputs. However, equation (5.16) results in the most appropriate explanation for the relationship between rice yield, current R&D expenditure, and R&D knowledge stock. The coefficients from this equation are used to calculate MIRR in the next chapter.

Table 5.3 Model Estimation for Rice Yield Function in Thailand, 1967-1998

Model	Coefficients						R-bar Squared	D.W.
	Constant Term	a_1	a_2	a_3	a_4	a_5-1		
Ln(Q/H) F Ir RD KRD H (5.4)	-2.99 (-1.54)	-0.03 (-0.57)	-0.04 (-0.44)	0.12 (4.49) **	0.27 (3.28) **	0.40 (3.04) **	0.91	2.20
Ln(Q/H) F Ir RD H (5.5)	-2.59 (-1.15)	0.06 (1.17)	.02 (0.22)	0.09 (3.13) **	-	0.38 (2.52) *	0.87	1.66
Ln(Q/H) F Ir KRD H (5.6)	3.76 (2.36) *	0.10 (1.86)	-0.06 (-0.44)	-	0.16 (1.52)	0.02 (0.17)	0.84	1.78
Ln(Q/H) F Ir H (5.7)	3.03 (1.95) *	0.13 (2.79) **	-0.01 (0.09)	-	-	0.07 (0.52)	0.84	1.69
Ln(Q/H) F RD H (5.8)	-2.55 (-1.15)	0.06 (2.52) *	-	0.09 (3.18) **	-	0.40 (2.92) **	0.88	1.68
Ln(Q/H) F KRD H (5.9)	3.70 (2.36) *	0.80 (2.18) *	-	-	0.15 (1.48)	-0.01 (-0.10)	0.85	1.78
Ln(Q/H) F RD KRD H (5.10)	-3.05 (-1.60)	-0.04 (-1.04)	-	0.12 (4.57) **	0.26 (3.31) **	0.37 (3.19) **	0.91	2.19
Ln(Q/H) F H (5.11)	3.03 (1.98) *	0.13 (6.79) **	-	-	-	0.06 (0.62)	0.84	1.69
Ln(Q/H) Ir RD KRD H (5.12)	-2.41 (-1.47)	-	-0.07 (0.97)	0.11 (5.14) **	0.25 (3.55) **	0.39 (3.04) **	0.91	2.20
Ln(Q/H) Ir RD H (5.13)	-4.11 (-2.21) *	-	0.13 (2.17) *	0.11 (4.29) **	-	0.40 (2.66) *	0.87	1.48
Ln(Q/H) Ir KRD H (5.14)	3.34 (2.03) *	-	0.10 (1.11)	-	0.24 (2.54) *	-0.07 (-0.59)	0.83	1.56
Ln(Q/H) Ir H (5.15)	1.63 (1.0)	-	0.31 (5.46) **	-	-	-0.06 (-0.41)	0.80	1.26
Ln(Q/H) RD KRD H (5.16)	-1.89 (-1.22)	-	-	0.10 (5.28) **	0.20 (4.29) **	0.31 (3.06) **	0.91	2.16
Ln(Q/H) RD H (5.17)	-7.60 (-7.63) **	-	-	0.14 (7.37) **	-	0.71 (13.10) **	0.86	1.40
Ln(Q/H) KRD H (5.18)	3.30 (2.00) *	-	-	-	0.33 (6.35) **	-0.01 (-0.13)	0.83	1.39

Source: Appendix C

Notes: 1) All variables are in natural logarithm form

2) * is significant at the 5% level, ** is significant at the 1 % level.

3) The figures in parentheses are t-values.

The estimated chemical fertilizer response function confirms that irrigated area, current R&D expenditure, R&D knowledge stock induce greater fertilizer application (table 5.4). The estimated coefficient of irrigated area is the most statistically significant. If the irrigated area increases by 1 percent, chemical fertilizer usage rice field will increase from 1.16 to 1.27 percent. Current R&D expenditure also shows a positive significant effect on chemical fertilizer use. If the current R&D increases by 1 percent, chemical fertilizer usage will increase from 0.27 to 0.31 percent. R&D knowledge stock has a positive significant effect on rice yield as expected. If the R&D knowledge stock increases by 1 percent, chemical fertilizer usage in rice field will increase by 0.92 percent. However, the estimated coefficient of hectarage is not significant in the fertilizer response function. The results indicate that chemical fertilizer, irrigated area, current R&D expenditure and R&D knowledge stock are complementary inputs to be used to determine rice yield increase.

Table 5.4 Model Estimation for Chemical Fertilizer Response Function, 1967-1998

Model	Coefficients					R-bar Squared	D.W.
	Constant Term	A_6	A_7	A_8	A_9		
LnF Ir RD KRD H (5.19)	-20.95 (-3.14) **	1.16 (3.71) **	0.31 (3.63) **	0.92 (3.25) **	0.32 (0.61)	0.97	1.38
LnF Ir RD KRD (5.20)	-17.09 (-8.24) **	1.27 (5.11) **	0.27 (4.56) **	0.92 (3.31) **	-	0.97	1.31

Source: Appendix C

Notes: 1) All variables are in natural logarithm form

2) * is significant at the 5% level, ** is significant at the 1 % level.

3) The figures in parentheses are t-values.

5.6 Granger Causality Test

The findings of the cointegration test show that all variables pass the eigenvalue and trace tests in the Johansen procedure. These results indicate that cointegrating vectors exist; however, the direction of the causal relationship between the variables is not mentioned. This is of particular importance between R&D expenditure, R&D knowledge stock and paddy yield; therefore, it is necessary to test for Granger causality.

According to Granger (1988), if a pair of series is cointegrated, then there must be Granger-causation in at least one direction. In this study, the role of R&D expenditure contributing to paddy yield is paramount. It is necessary to confirm whether changes in one variable cause changes in another and vice versa. Therefore, the equations are set to ascertain the direction of causality between paddy yield and R&D expenditure.

The stationary test of all series are represented as I (1), stationary is induced in the series stationary is induced in the series by taking first differences by taking first differences. Thus, the model specifications of Gordon (1988), Mehra (1994), and Schimmelpfenning and Thirtle (1994) are applied. This is known as the "standard" Granger-causality test. This specification assumes that all variables in the model are stationary. The stationary test of all pertinent variables indicates that the series are I (1), . Hence, the presence of Granger-causality is investigated by estimating paddy yield and R&D expenditure in is general form:

$$y_t = \sum_{s=1}^{n1} \beta_{1s} y_{t-s} + \sum_{s=1}^{n1} \beta_{2s} RD_{t-s} + U_t \tag{5.32}$$

$$RD_t = \sum_{s=1}^{n2} \gamma_{1s} RD_{t-s} + \sum_{s=1}^{n2} \gamma_{2s} Y_{t-s} + V_t \tag{5.33}$$

where $\ln Y_t$, is the paddy yield and $\ln RD_t$ is R&D expenditure or R&D knowledge stock. U_t and V_t stand for white noise error terms, n1-n2 are the order of lags. As the series for $\ln Y_t$, $\ln RD_t$ and $\ln KRD_t$ are I(1), I(2) and I(3) respectively, the equations can be written as follows:

$$\Delta \ln y_t = \sum_{s=1}^{n1} \beta_{1s} \Delta \ln y_{t-s} + \sum_{s=1}^{n1} \beta_{2s} \Delta\Delta \ln RD_{t-s} + U_t \tag{5.34}$$

$$\Delta\Delta \ln RD_t = \sum_{s=1}^{n2} \gamma_{1s} \Delta\Delta \ln RD_{t-s} + \sum_{s=1}^{n2} \gamma_{2s} \Delta \ln Y_{t-s} + V_t \tag{5.35}$$

The equations for R&D knowledge stock are:

$$\Delta \ln y_t = \sum_{s=1}^{n1} \beta_{1s} \Delta \ln y_{t-s} + \sum_{s=1}^{n1} \beta_{2s} \Delta\Delta\Delta \ln KRD_{t-s} + U_t \tag{5.36}$$

$$\Delta\Delta\Delta \ln KRD_t = \sum_{s=1}^{n2} \gamma_{1s} \Delta\Delta\Delta \ln KRD_{t-s} + \sum_{s=1}^{n2} \gamma_{2s} \Delta \ln Y_{t-s} + V_t \tag{5.37}$$

For there to be unidirectional causality from R&D to rice yield, the estimated coefficients on lag R&D in equation (5.32) must be significantly different from zero, that is, all $\beta_{2s} \neq 0$. However, rice yields do not Granger-cause R&D if γ_{2s} in equation (5.33) = 0. If $\beta_{2s} \neq 0$ and $\gamma_{2s} \neq 0$, there is bilateral causality between R&D and rice yield, and if β_{2s} and γ_{2s} are not significantly different from zero, R&D and rice yield are independent. The hypothesis can be tested using the standard Wald F-statistic as follows:

$$F_s = \frac{(ESSR - ESSUR)/n}{ESSUR/(m-k)} \tag{5.38}$$

where ESSR and ESSUR are the sums of square residuals in the restricted and unrestricted regression respectively, m is the number of observations, k is the number of estimate parameters in the unrestricted regression.

The Granger causality is performed using annual time-series data for the period 1967-1998. The test results are reported in Table 5.5. The results show that when the appropriate number of lag length is determined, R&D expenditure and R&D knowledge stock Granger cause rice yield. The F-statistic from R&D expenditure to rice yield are statistically significant at the 5 percent level in the case of lag 2 and 3, and statistically significant at the 10 percent level in the case of lag 4. The F-test from R&D knowledge stock to rice yield is statistically significant at the 10 percent level in the case of lag 3. These results show R&D expenditure and R&D knowledge stock Granger cause rice yield.

The possibility of the Granger-causality tests of the reverse directions from rice yield to determining variables are also reported in Table 5.5. The null hypothesis states that rice yield change in equation (5.33) can not be rejected for the determined lags at a reasonable level of significance. These results suggest that there is a unidirectional causality running from R&D expenditure to rice yield in the case of lag 2 and 4. The tests show that R&D expenditure is Granger prior to rice yield, but rice yield is not Granger prior to R&D expenditure. However, the results suggest that there is a bilateral causality between R&D expenditure and rice yield in the case of lag 3. The tests show that R&D expenditure is Granger prior to rice yield, and rice yield is Granger prior to R&D expenditure. These results support the cointegration results for the relationship between rice yield and R&D investment.

In the case of causality of R&D knowledge stock, the F-statistic from R&D knowledge stock to rice yield and vice versa is statistically significant at the 10 percent level in the case of lag 3. These results show that there is bilateral causality between R&D knowledge stock and rice yield.

In conclusion, the Granger's causality test shows that R&D expenditure and R&D knowledge stock is causally prior to rice productivity and vice versa. These findings are as expected and the direction of the relationships between R&D expenditure and R&D knowledge stock and rice yield encourages policy designs which emphasise R&D investment as a determinant of yield growth.

Table 5.5 Granger-causality Test: The Standard Case

Lag	R&D→ Yield		Yield → R&D		KRD→ Yield		Yield → KRD	
	F_S	d.f	F_S	d.f	F_S	d.f	F_S	d.f
2	3.50**	2, 25	1.32	2, 24	2.50	2, 23	1.32	2, 23
3	4.27**	3, 22	3.33**	3, 21	3.00*	3, 20	3.00*	3, 20
4	2.50*	4, 19	2.52*	4, 18	1.80	4, 17	2.09	4, 17

Source: Appendix E

Notes: * is significant at the 10% level, and ** is significant at the 5% level

5.7 Conclusion

This study used time series data to investigate the relationship between rice productivity and determining inputs. The rice yield response function was formed from the Cobb-Douglas production function. Chemical fertilizer, irrigated area, R&D expenditure, R&D knowledge stock, and harvested area are the explanatory variables involed in the rice yield response function. The relevant time series data sets are tested by modern econometric techniques (Dicky-Fuller unitroot test, the Cointegration approach of Johansen, and Granger-Causality) to determined whether the data is stationary and cointegrated. The Granger-Causality test is used to surmise the direction of causality. The data used in this study is macro-level or aggregate data between 1967 and 1998. The major sources of this data are various issues of "Agricultural Statistics of Thailand, Year Book", previous studies, and occasional OAE surveys.

Before the cointegration and causality analysis are applied, the order of integration for each of the variables in equations (5.4) to (5.20) are determined. The presence of unit roots in level is not rejected for each series at the 5 percent level by ADF. However, when all time series are in various differences, the presence of unit roots is rejected at the 5 percent level. It is concluded that the time series in empirical models (5.4) to (5.20) are nonstationary in the levels but stationary in the first, second and third differences.

The multivariate cointegration test using Johansen's method shows that all variables pass the eigenvalue and trace tests. These results indicate that the cointegrating vector exist. It can be concluded that chemical fertilizer usage, irrigated area, R&D expenditure, R&D knowledge stock, and hectarage interact in the generation of rice yield equations. There are stable long-run relationships among all variables in equations (5.4) to (5.20). When the OLS method is applied to test the statistical significance of coefficients for each equation, three equations {(equation (5.8), (5.13), and (5.16)} perform sensible regressions. All of the estimated coefficients show the expected signs and are statistically significant. The yield equation (5.16) comprising of current R&D expenditure, R&D knowledge stock, and hectarage has the best fit, and is used to calculate the contribution of R&D to rice yield.

Moreover, the estimated fertilizer response functions (equation 5.19 and 5.20) show irrigated area, current R&D expenditure, R&D knowledge stock are the main factors in determining chemical fertilizer utility in rice cultivation. This implies that all explanatory variables: chemical fertilizer, irrigated area, current R&D expenditure, and R&D knowledge stock are related and are able to be used as the complementary inputs to increase rice yield.

Finally, the causal relationships between current R&D expenditure and R&D knowledge stock and rice yield were tested. The results show that current R&D expenditure is Granger prior to rice yield and vice versa. Moreover, there are lengthy lag times between R&D investment and rice yield. This is a crucial factor to determine the flow of benefits generated from R&D. These results are as expected and the direction of the relationship supports popular beliefs.

CHAPTER 6

RETURNS TO R&D AND IMPLICATIONS FOR POVERTY REDUCTION

6.1 Introduction

The results of cointegration reported in Chapter 5 indicate that all time series data in equations (5.4) to (5.20) are cointegrated in the long-term. These results indicate that the estimate of the cointegrating vectors appears to exist and both current R&D expenditure and R&D knowledge stock directly affect rice yield growth. The yield equation consisting of current R&D expenditure, R&D knowledge stock, and hectarage best explains rice yield and measures the contribution of R&D investment to improvements in rice yield. Thus, the purpose of this chapter is to use the rice productivity coefficients presented in Chapter 5 to calculate the rates of return on R&D investment on rice in Thailand during 1967-1998.

The chapter is divided into two sections. In the first section, returns of R&D investment are calculated using a standard formula to find the marginal internal rate of return (MIRR) using two approaches. The first approach uses R&D expenditure, an appropriate time lag length and shape, and partial coefficients to calculate the flow of the marginal value of productivity (MVP) over the time lag length. The second approach incorporates the elasticity of rice yield with respect to R&D knowledge stock and the period of depreciation of R&D knowledge stock. Using the latter approach, the MVP is also calculated over the period of depreciation. In the second section, the impact of rice yield improvements on poverty alleviation is analysed. Finally, the conclusions of the chapter are drawn.

6.2 The Rate of Return on Rice R&D

Many studies using the production function approach to study the contributions of R&D have treated R&D (and extension) as an explanatory variable that affects output or productivity growth. The models have been estimated by obtaining the parameters of aggregate production functions. The stream of benefits are calculated from the marginal product or output elasticity with respect to R&D expenditure in the past.

Once the obtained parameters have been found, two steps are taken to estimate the marginal internal rate of return (MIRR). Firstly, the value of marginal product (VMP) of research is estimated by multiplying the coefficient of research attributed in production function by the average product of research. Secondly, the MIRR, which is defined as the interest rate that causes the net present value of R&D you already gave the defenetion investments to be equal to zero, is calculated using the stream of VMP.

However, technological change resulting from R&D expenditures occurs over time and its impact on output and productivity occur continuously. The major source of variation among production function studies is the time lag profile reflecting the impact of R&D and extension expenditure on production output or productivity. Therefore, before the MIRR can be estimated, the R&D lag must be considered as it is a crucial factor in determining the stream of benefits from R&D investment.

According to Davis (1981), Thirtle and Bottomley (1989), Alston *et al.* (1995), Fernandez-Cornejo and Shumway (1997), Makki *et al.* (1999), and Thirtle (1999), the marginal internal repetitive rate of return (MIRR) is defined as the discount rate that causes the net present value of R&D investments to be equal to zero. The MIRR is calculated from the value of marginal product (VMP) using the stream of marginal products. In this case, the rice yield elasticity of R&D must be converted into the VMP before the MIRR is calculated. The marginal physical product of R&D can be expressed as the productivity elasticity of R&D multiplied by average physical product:

$$MP_{RD,t-i} = \frac{\partial Y_t}{\partial RD_{t-i}} = \alpha i \left(\frac{\overline{Y_t}}{\overline{RD_{t-i}}}\right) \tag{6.1}$$

where α_i is the productivity elasticity of R&D expenditure for year i, the ratio of $\overline{Y_t}$ and $\overline{RD_{t-i}}$ is an average value (geometric mean) of productivity and R&D expenditure over the period. This marginal product of R&D must be converted into the value of marginal product (VMP). Thus, both sides of (6.1) are multiplied by the change in value of output (ΔV), from the beginning to the end of the period, divided by the change in the value of productivity (ΔY) over the period. Hence, the $VMP_{RD,t-i}$ can be calculated as follows:

$$VPM_{RD,t-i} = \alpha\ i\left(\frac{\overline{Y}}{\overline{RD_{t-i}}}\right)\left(\frac{\Delta V}{\Delta Y}\right) \tag{6.2}$$

A standard assumption in production economics is that an estimated production function with output and all inputs measured in physical units will give the VMP as the marginal product multiplied by the product price (Davis, 1981). Thus, $(\frac{\Delta V}{\Delta Y})$ can be approximated by the output price (Pq) (Makki *et al,* 1999). Hence, equation (6.2) becomes:

$$\mathrm{VPM}_{t\text{-}i} = (\alpha_i \frac{\overline{Y_t}}{RD_{t-i}}) \mathrm{Pq} \tag{6.3}$$

where $\mathrm{VPM}_{t\text{-}i}$ is the value of the marginal product of R&D knowledge stock at time t-i, α is the rice yield elasticity with respect to R&D knowledge stock, which is constant over the period $\frac{\overline{Q_t}}{KRDL_{t-i}}$ and can be estimated by the geometric mean value of these variables (Thirtle and Bottomley, 1989; Thirtle 1999), Pq is the geometric mean value of real price of rice per kilogram (1987 price) over the period (Makki *et al,* 1999).

The formula to calculate the MIRR with a finite lag which causes the net present value of a unit of an investment to be equal to zero is

$$\sum_{i=1}^{n}[VMP_{t-i}/(1+r)^i]-1=0 \tag{6.4}$$

where n is the average lag length for each R&D knowledge stock term, and the MIRR for a one unit change in R&D knowledge stock is calculated by solving for r.

According to Peterson (1967), the VMP is not attained for a period of n year after the expenditure, but the return continues into perpetuity. As such, the formula to calculate the MIRR when the lag length is infinite is:

$$VMP_{t-i}[\sum_{i=1}^{\infty}1/(1+r)^i]=0 \tag{6.5}$$

In this study, two approaches are used to calculate MIRR. The first approach is a traditional method, where the calculated MIRR depends upon the lag profile, partial coefficients, and R&D expenditure. In the second approach the productivity elasticity of R&D knowledge stock, and the period of its depreciation are used to calculate the MIRR.

6.2.1 Traditional Approach

The conventional approach to measuring the contribution of agricultural R&D to output or productivity uses R&D expenditure as a research variable incorporating a time lag structure. The major source of variation among production function studies is the time lag structure used to reflect the impact of R&D and extension expenditure on production output or productivity. The early studies of the time lags of agricultural R&D expenditure on output by Griliches (1964), used either a single year's lagged expenditure or a simple average of two previous years. To allow for a lag in the effect of the expenditure, Griliches averaged the flow of expenditures in the previous year with the level six years previously. After that, Evenson (1968), Fishelson(1971), Bredahl(1975), Cline (1975), and Cline and Lu(1976) estimated the effect of lagged research in U.S. agriculture to be an ' inverted V-shaped' or ' inverted U-shaped' lag structure with a mean lag of 6-7 years and the effect declining to zero in the 13-14 th year.

However, there is no agreement in the literature concerning the length and shape of the lag structure. According to Evenson (1988), the lag structure differs depending on the kind of research (basic and applied research), types of commodities, and research output. The distributed lag between R&D expenditure and output or productivity can be classified into four periods: (a) the lag between research spending and research output (b) the lag between research output (new technology) and full adoption (c) the lag period of the growth of the new technology (d) the lag period of depreciation or obsolescence of new technology. Moreover, Evenson (1988) pointed out that there is little theory to guide empirical studies on the spatial and chronological dimension of research variables.

In this approach, the Almon (1965) or polynomial distributed lag technique of second-degree polynomial function is applied as its lag has a rather general formulation (Gujarati, 1995; and Pindyck and Robinfeld, 1998). Moreover, this choice is also supported by Cline (1975: 69), Thirtle and Bottomley (1989), and Thirtle (1999) as the production-oriented research lag gives a clear indication of the appropriate degree of time lag structure.

According to Almon (1965), the general form of the distributed lag model is

$$Yt = \alpha + \beta 0Xt + \beta 1Xt\text{-}1 + \beta 2Xt\text{-}2 + \ldots + \beta kXt\text{-}k + ut \qquad (6.6)$$

which may be written as

$$Yt = \alpha + \sum_{i=0}^{k} \beta iXt\text{-}i + ut \qquad (6.7)$$

This model includes one or more lagged values of the dependent variable among its independent variables where Yt is the dependent variable, and Xt-i is the independent variable.

Following Weierstrass' theorem in mathematics, Almond assumes that βi can be written as

$$\beta i = a_0 + a_1 i + a_2 i^2 \qquad (6.8)$$

Substituting (6.8) into (6.7) gives

$$Yt = \alpha + \sum_{i=0}^{k} (a_0 + a_1 i + a_2 i^2)Xt\text{-}i + ut$$

$$= \alpha + a_0\sum_{i=0}^{k} Xt\text{-}i + a_1 i \sum_{i=0}^{k} Xt\text{-}i + a_2 i^2 \sum_{i=0}^{k} Xt\text{-}i + ut \qquad (6.9)$$

$$\text{Let } Z0t = \sum_{i=0}^{k} Xt\text{-}i,\ Z1t = \sum_{i=0}^{k} Xt\text{-}i,\ Z2t = \sum_{i=0}^{k} Xt\text{-}i$$

$$\text{then } Yt = \alpha + Z0t + a_1 Z1t + a_2 Z2t + ut \qquad (6.10)$$

In this way Yt is regressed on the variables Z, not the X variable with OLS procedure and we obtain the value of α and a_i in (6.10). The parameters of the lagged model can be estimated as follows:

$$\beta o = a_0$$
$$\beta 1 = a_0 + a_1 + a_2$$
$$\beta 2 = a_0 + 2a_1 + 4a_2$$
$$\beta 3 = a_0 + 3a_1 + 9a_2$$
$$\cdots\cdots\cdots\cdots$$
$$\beta k = a_0 + ka_1 + k^2 a2$$

The Almon technique requires knowledge of the maximum length of the lag k first. Gujarati (1995: 615), believes the lag length can be determined by following the advice of Davidson and MacKinnon (1993: 675-676): " The best approach is probably to settle the question of lag length first, by starting with a very large value of q (the lag length) and then seeing whether the fit of the model deteriorates significantly when it is reduced without imposing any restrictions on the shape of the distributed lag" According to Cline (1975:69), the criterion to select the best lag is based upon Theil's R^2 (to choose the minimum standard error of estimate). This statistic steadily declines as the lag length is increased until reaching a minimum at a length of the year.

In this study, the Almond technique is used to capture the lag structure of rice R&D expenditures and paddy yield using time-series data from 1967 to1998 and 1950 to 1998. However, this method fails to capture the lag profile, both lag length and shape because the distribution of partial coefficients do not give reasonable and significant results. In fact, several researchers including Evenson (1982) and Pochanukul (1992), also experienced these failures using R&D expenditures as a research variable.

However, when the time-series data of R&D knowledge stock during 1950 to 1998 is used, a second-degree polynomial and a 8-year lag can capture the lag structure between rice yield and R&D knowledge stock. The estimated coefficients (distributed lag coefficients) are the yield elasticities of the R&D variable for each year of the lag. The distributed lag coefficients of R&D knowledge stock without depreciation are approximately symmetrical and inverted-U-shaped as expected. The distributed lag coefficients are reasonable and statistically significant. The results are reported in Table 6.1. All distributed lag coefficients proved to be statistically significant at the 1 percent and the 10 percent level. The adjusted R-bar squared values suggest the R&D variable explains over 90 percent of the variance in rice yield. The Durbin-Watson statistic is within the acceptable region.

After solving equation (6.4) using distributed lag coefficients in Table 6.1 and 8-years for the lag length, the rate of return to R&D assuming no depreciation is 44.54 percent per annum (Table 6.4). This rate is high, and adequate to attract such investment.

Table 6.1: Distributed Lag Coefficients of R&D knowledge Stock.

Lag	Distributed Lag Coefficients of KRD
0	0.044
1	0.058
2	0.064
3	0.066
4	0.055
5	0.047
6	0.027
7	0.001
8	0.000
Z_0	0.044 (1.90)*
Z_1	0.017 (3.13)**
Z_2	-0.003 (-3.59)**
$\Sigma\alpha_i$	0.265
Adjusted R^2	0.90
D.W.	1.60

Source: Appendix C

Notes: 1) The figures in parentheses are t-values

2) * is significant at the 10 % level; ** is significant at the 1 % level.

6.2.2 Stock Approach with Depreciation

This approach to estimate the rate of return of R&D investment is based on the concept that current knowledge used to produce new technologies is an accumulated stock, which has been accumulated by past investments. An investment in agricultural R&D is an investment in maintaining or increasing this capital stock. The stock of knowledge increases agricultural output and productivity either immediately or with a time lag. The increase in productivity stems from research and development in new or improved hardware and software technology, which is issued in the form of new or improved outputs, inputs, or through other changes in farming techniques that are embodied in people, the organisation, and so on. The theoretical framework of this concept was discussed in Chapter 4.

Based on the theoretical framework reported in Chapter 4, agricultural R&D includes basic research in the biological and physical sciences, applied research, and development to generate new agricultural technologies. These processes continue to generate new knowledge which depend on the accumulation of the previous investments in knowledge creation together with the current investment in knowledge generation. The final aim of agricultural R&D is to assist innovation, product improvement, and operational improvement for agricultural production.

The above concept can be represented in terms of an agricultural production function in which R&D knowledge stock is an input variable in the function along with the conventional inputs such as land, labor, fertilizer, irrigation, and so on. This production function is transformed into a yield function, presented in equation (5.2). The stream values of the marginal product of R&D knowledge stock estimated from the yield function represent the increase in the value of agricultural due to an increase in the knowledge stock of one unit. The evaluation of the R&D knowledge stock is the present value of the stream of benefits it generates in the future. The formulae in equations (6.1) to (6.5) then are used to calculate the rates of return to R&D investment.

This study attempts to apply the R&D knowledge stock formulation using the sum of past investments in R&D and its depreciation, to calculate the returns from agricultural R&D. In this approach, R&D knowledge represents a research variable which determines rice yield. In the literature, R&D knowledge stock is viewed as research capital, which is derived from the output side of research in the form of new knowledge and technology, while R&D expenditures, scientists, laboratories are classified as research inputs. Thus, to evaluate the contribution of R&D to output or productivity, either study, the input side (R&D expenditures) the output side or the input side of research is selected. In this and output side are selected to evaluate the contribution of R&D for conventional approach, while the output side (R&D knowledge stock with depreciation concept) is employed in the stock approach.

Evenson and Kislev (1975), Grilliches (1979), and Evenson (1980,1982) constructed research variables under this stock concept. Evenson and Kislev (1975) measured research knowledge by the number of scientific publications. Grilliches (1979) proposed a model for industrial firms by introducing two separate variables for research capital: specific knowledge capital for a firm (Ki) and the state of aggregate knowledge of the relevant industry (Ka = a Ki). For any firm, specific knowledge capital has a polynomial lag distribution representing an index of current and past research expenditures. Evenson (1980, 1982) defined the research variable as research capital constructed from a specific lag structure. Setaboonsarng and Evenson (1991) constructed a research variable for regional research capital for all crops. This research capital is an accumulative research expenditure characterised by a specific lag structure (inverted V-shaped) with weights. Pochanukul (1992) formulated research capital from R&D expenditures by assuming a time lag length and shape similar to Setaboonsarng and Evenson (1991).

While the R&D knowledge stock grows each year, it also depreciates over time. A well known depreciation rate formula is used to construct the R&D knowledge stock measure at various rates of depreciation:[18]

$$KRD_t = (1 - \delta)KRD_{t-1} + RD_t \tag{6.11}$$

where KRD $_{t-1}$ is the R&D knowledge stock at time t, which is the stock at t-1 plus RD_t, RD_t is the volume of R&D expenditures in year t, and δ is the depreciation rate. The alternative R&D knowledge stock taken in this study uses the straight line method of depreciation at a rate of 5 percent and 10 percent.

The results show a significant positive relationship between R&D knowledge stock and rice yield. This implies positive payoffs to R&D investment in rice. The rates of return on R&D investment are based on the coefficients obtained from the OLS method of estimation. The coefficients of R&D knowledge stock with a zero, five, and ten percent depreciation rate are statistically significant at the 5 and 1 percent level and are reported in Table 6.3.

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[18] Most studies of the relationship between R&D and productivity in industrial sector have argued that the R&D knowledge stock does not depreciate (Griliches, 1988; Sterlacchini, 1989). However, Bosworth (1976); Pakes and Schankerman (1984) suggest that depreciation rate of 10 per cent would be more appreciate. More details are in Cameron and Muellebauer (1996).

However, there are lags of several years between the R&D expenditure and the benefits to production and productivity due to increased knowledge or to new technology. As such, the effect of a particular investment today can persist over many future production periods. Nevertheless, the concept of the lag structure in agricultural R&D remains controversial (Kingwell, 1999). Furthermore, according to Alston *et al* (1996 and 1998), the use of a finite lag is inappropriate and leads to biased coefficients. In addition, the interpretation of coefficients on lagged research and extension variables is not clear. Alston *et al* also suggested there are long lags between R&D investments and their eventual effects on the stock of useful knowledge and production.

Table 6.2 Estimated Equations for R&D Knowledge Stock at Various Depreciation Rates

Depreciation Rate (% per annum)	Estimated Coefficients				R-bar Squared	D.W.
	Constant	a_3	a_4	a_5		
0	-1.89 (-1.22)	0.10 (5.28)**	0.20 (4.29)**	0.31 (3.06)**	0.91	2.16
5	-6.68 (-7.88)**	0.11 (6.32)**	0.28 (3.93)**	0.55 (9.07)**	0.90	1.99
10	-9.53 (-8.28)**	0.12 (5.75)**	0.18 (2.70)*	0.76 (14.56)**	0.88	1.71

Sources: Table C.13, Table C.16, Table C.17 (Appendix C)

Notes: 1. a_3 = yield elasticity of R&D expenditure, a_4 = yield elasticity of R&D knowledge stock, a_5 = yield elasticity of hectarage

2. The figures in parentheses are t-values

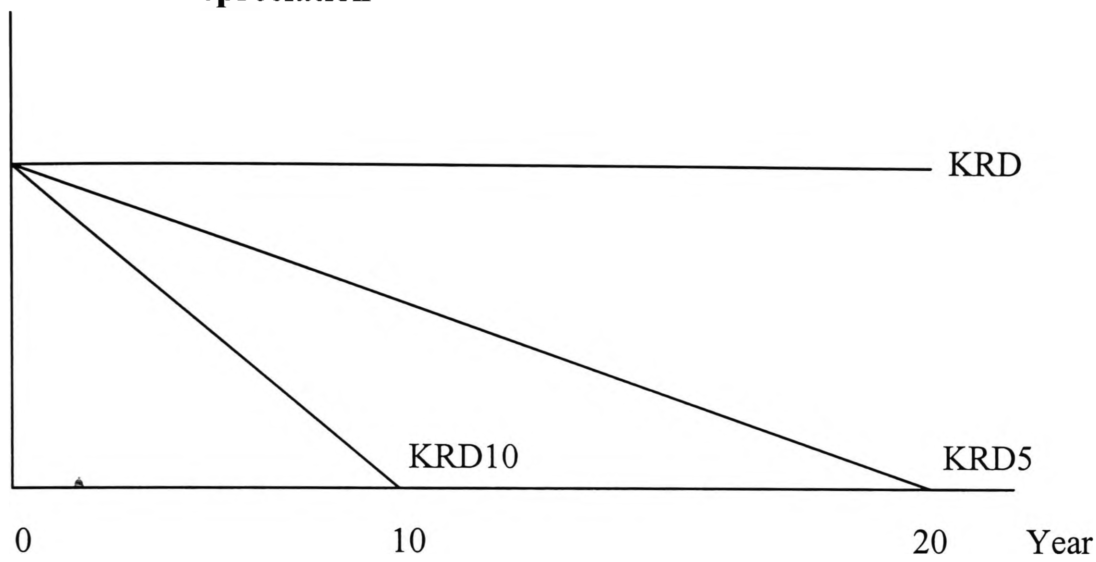
3. * is significant at the 5% level, ** is significant at the 1 % level.

In Chapter 3 and 4, we assumed that there is a R&D knowledge stock which accumulated from the sum of past investments in R&D. This R&D knowledge stock is represented by embodied R&D resources in human ability (agricultural scientists and staff), R&D organisations, and information to create new knowledge or new technologies in the future. Changes in knowledge have long lasting impacts as there is a dynamic relationship between today's research investment and future productivity. A stream of benefits occurs over time associated with past and current investment in R&D. However, this knowledge stock can also become obsolete as new knowledge replaces the old. In this study, R&D knowledge stock is used rather than R&D expenditure with a specific time lag.

The period of R&D depreciation is assumed to be the length of time R&D knowledge stock of a given year can affect rice yield, that is, the lag period of depreciation or obsolescence of new technology. It is also assumed that R&D knowledge stock affects rice yield immediately as the existing stock of knowledge accumulated from past investments, and the new technology generated from R&D knowledge stock has already emerged and is continuously used to improve rice yield. Thus, the period of the distributed lag between R&D expenditure and rice yield is in period (a)…lag between research spending and research output, and in period (b)…the lag between research output (new technology) and full adoption, is eliminated in this approach. This view assumes R&D knowledge stock gradually depletes and is obsolete at the end of the period of R&D depreciation. It is implied that the R&D knowledge stock with zero depreciation continues to affect rice productivity forever. Thus, R&D knowledge stock with a one per cent depreciation rate per annum will affect rice productivity for 100 years. Similarly, R&D knowledge stock depreciating by five, and ten percent per annum will affect rice productivity for 20, and 10 years respectively. Therefore, the period of R&D knowledge used to calculate MIRR in this study are infinity, 20, and 10 years. The R&D knowledge stock with a zero depreciation rates per annum is assumed for the infinite lag length. The R&D knowledge stock with a depreciation rate of five, and ten percent have finite lag lengths of 20 and 10 years respectively. Two different types of lags are used in different formula to calculate the MIRR in equations (6.4) and (6.5). Thus, to calculate the marginal internal rate of return (MIRR), average lag lengths and the period of depreciation of R&D knowledge stock are used.

Given the detailed concepts above and views from several previous studies, this study assumes the sum of current and the past investments in R&D to be a proxy for R&D knowledge stock. One unit of R&D knowledge stock with depreciation gradually declines by a constant proportion until it reaches zero at the end of the depreciation period, while R&D knowledge stock with no depreciation continues perpetually. The lag lengths and shapes of the contribution of R&D knowledge stock detailed above are drawn in Figure 6.1

Figure 6.1: Lag Profiles of R&D Knowledge Stocks with and without Depreciation



KRD = R&D Knowledge Stock Without Depreciation.

KRD5= R&D Knowledge Stock With a 5 Per cent Depreciation Rate

KRD10= R&D Knowledge Stock With a 10 Per cent Depreciation Rate

Distributed lag coefficients are determined by multiplying the weighted contribution to rice yield with the estimated R&D elasticities of rice yield (Table 7.3). The distributed lag coefficients start at the first year at one weight, which then declines proportionally in the following years. For example, it takes twenty years for linear depreciation of R&D knowledge of five percent depreciation rate. The weighted contribution to rice yield starts at one, and then proportionally declines to 0.95, 0.90, and so on, until it reaches 0.05 at the end of the depreciation period in 20 years. The weighted contribution to rice yield and distributed lag coefficients of R&D knowledge stock with five and ten per cent depreciation rates are reported in Table 6.3.

After solving equations (6.4), and (6.5) using the distributed lag coefficients in Table 6.3 and the period of depreciation rate as the lag length, the estimated MIRR are reported in Table 6.4. R&D knowledge stock with zero, five, and ten per cent depreciation rates generate MIRRs of 17.93, 25.72 and 36.42 percent respectively. These results suggest rice R&D investment as an attractive public investment as the calculated MIRRs are high for investments of this nature[19]. Moreover, if the magnitude of R&D knowledge stock decreases, MIRR increases. This implies the estimated MIRR is inversely related to the R&D knowledge stock. The less R&D knowledge stock there is, the higher the return obtained. As such, this study suggests that decreasing R&D knowledge stock corresponding with increases in MIRR due to knowledge obsolescence, is an indication of under-investment[20] as hypothesized in this study.

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[19] Ruttan (1982: 241) assembled the results of a large number of studies of the contribution of research to productivity growth which indicated high rates of return to investment in agricultural research --- above the 10 to 15 percent that private firms consider adequate to attract investment and the rate of return to research investment.

[20] Boyce and Evenson (1975: 116-7) wrote "... the extraordinarily high rates of return that have been measured in virtually all of the studies of agricultural research productivity must be taken to show that investment levels have been too low to represent efficient allocation of scare resources." Pinstrup-Andersen, 1982:101; and Echeverria, 1990: 20) stated "...The high pay offs suggest that agricultural research and extension have been very productive. These also means that had there been more funds for research, the returns would have been lower, i.e., the amount investment has been sub-optimal." More recently, Alston and Pardey (1996: 219) concluded that "... it seems likely that the rate of return to agricultural R&D has been relatively high, and that there has been some under-investment."

Table 6.3: Weighted Contribution to Rice Yield and Distributed Lag Coefficients

Year	Weighted Contribution to Rice Yield (5% Depreciation Rate)	Distributed Lag Coefficients*	Weighted Contribution to Rice Yield (10% Depreciation Rate)	Distributed Lag Coefficients*
1	1.00	0.28	1.00	0.18
2	0.95	0.27	0.90	0.16
3	0.90	0.25	0.80	0.14
4	0.85	0.24	0.70	0.13
5	0.80	0.22	0.60	0.11
6	0.75	0.21	0.50	0.09
7	0.70	0.20	0.40	0.07
8	0.65	0.18	0.30	0.05
9	0.60	0.17	0.20	0.04
10	0.55	0.15	0.10	0.02
11	0.50	0.14	-	-
12	0.45	0.12	-	-
13	0.40	0.11	-	-
14	0.34	0.10	-	-
15	0.30	0.08	-	-
16	0.25	0.07	-	-
17	0.20	0.06	-	-
18	0.15	0.04	-	-
19	0.10	0.03	-	-
20	0.05	0.01	-	-

Note: * is calculated by multiplying the weighted contribution to rice yield with the R&D elasticity of rice yield

Table 6.4: MIRR at Various Depreciation Rate

Depreciation Rates	Estimated MIRR (%) for Stock Approach	Estimated MIRR (%) for Conventional Approach
0	17.93	44.54
5	25.72	
10	36.42	

Source: Appendix I

The estimated MIRR in this study is associated with several studies reported in Chapter 4. Ruttan (1982) reported that in over sixty studies the rates of return to agricultural R&D investment were mostly between thirty and sixty per cent using both the cost-benefit approach and the production function approach. Harris and Lloyd (1991) reported real rates of return from research from several empirical studies were found to be in the order of 30 percent to 70 percent per annum and sometimes even higher. Echeverria (1990) presented published studies on the returns to agricultural research in more than 100 cases throughout the world since the late 1950's. He reported that many studies have shown a high payoff to agricultural research investment, with rates of return above 50 percent. Compared to previous studies on returns to investments in agricultural research on a wide range of commodities at the national, and international level, the estimated results of this study indicate that rates of return to rice R&D investment in Thailand are adequate but still indicate under-investment. This may be partly due to under-investment in rice R&D in the past, particularly during the 1970's when R&D expenditures dropped sharply.

The estimated rates of return to rice R&D investment in this study are rather high using both the conventional stock approaches. This means that rice R&D investment in Thailand has been under-financed and sub-optimal (Echeverria, 1990:20; and Ruttan, 1982:24). Thus, rice yield in Thailand remains low because the rice R&D policy in Thailand has emphasized improvements on rice quality rather than on rice yield increases. This is similar to the findings of IRRI (1993:100) who state "The emphasis on grain quality is the main reason for the low adoption rate of modern, high-yielding rice varieties in Thailand." This study suggests that rice R&D aimed at improving rice yield in Thailand has been low. Very low rice yields in Thailand can be partly attributed to insufficient R&D investment in the past.

However, which rates are moderate compared to previous studies. Setaboonsarng and Evenson (1991) and Pochananukul (1992) used the OLS method and reported high rates of returns on R&D investment on agriculture and rice in Thailand of around 40 and 45 percent respectively. The results of this study are associated with the two previous studies that provided high rates for an investment of this nature.

6.3 Implication of Rice Yield for Poverty Alleviation

Improving the living standards of the poor in countries like Thailand is one of the most important governmental tasks. Agricultural R&D plays a very important role in this task as the agricultural sector provides the basis for economic development. The majority of the poor work in the agricultural sector, and sufficient food supply is central to reducing rural poverty. Agriculture continues to be the main source of income for the majority of people in the country, however poverty in developing countries is found in both agricultural and non-agricultural sectors. Absolute poverty is measured as an insufficient calorie intake according to predetermined objective norms.

It is widely accepted that agricultural R&D provides the potential to expand food production and improve productivity in developing countries. It is also believed that agricultural R&D is capable of contributing large gains to the society in term of food supply, economic growth and improvement of living standards. Based on these reasons, the society as a whole may obtain large indirect socio-economic gains from agricultural R&D. Thus, the role of agricultural R&D in poverty alleviation also needs to be examined.

The impact of agricultural R&D on economic development and structural change is complex, operating indirectly through several channels and depending upon a variety of conditioning factors (Kerr and Kolavalli, 1999). Pinstrup-Anderson (1982) stated that the relationships between agricultural research and food production, economic growth, nutrition, and income distribution are complicated. Based on the above statements, the present study of the impacts of rice R&D on rice yields cannot deal with economic development or externalities of rice R&D. These, therefore, are beyond the scope of this study. However, this section is an attempt to estimate the impact of rice R&D investment on the poverty level[21] through the increase of rice yield. It is believed that policy makers are concerned with the impact of agricultural R&D investment on productivity, which in turn can increase income and alleviate poverty. An understanding of these relationships is essential in utilising R&D as effectively as possible to achieve economic and social development.

Although many studies show that research-led technological improvement have helped to increase agricultural productivity and food production in developing countries, many people still question the role of agricultural R&D in alleviating poverty. Lipton and Longhurst (1989) discussed the impact of new seeds on poor people. Evidence from plant breeding, economics, and nutrition science was used to

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[21] A conventional way to measure poverty is to establish a poverty line, defined as the minimum level of income needed to satisfy basic subsistence requirements, and to count the number of people below that line (Sen 1981).

to pinpoint the achievements of the green revolution. They concluded that the technical features of the modern varieties (MVs) created more employment, cheaper food and lower risks for small farmers. However, if MVs are used in unsuitable areas, they may bring new problems to the agricultural sector. Firstly, the MVs reduce crop diversity which may increase the dangers from pests and insects. Secondly, workers are displaced as income from MVs help farmers to obtain labor-saving inputs such as herbicides and threshers. Thirdly, some researchers may emphasise grain quality, rather than increase in the yield, robustness, or regional spread of MVs. The problems may cause poverty in some areas to increase. However, Lipton and Longhurst suggested that technological break-through alone would not solve the deep-rooted social problems of the poor. Rather technical features combined with socio-economic issues as new packages of policies and new research priorities will increase the power of the rural poor.

Hossain (1998) assessed the impact of rice research on food grain production and the well - being of the people in Bangladesh. He concluded that between 1987 and 1994-a period of rapid technological progress - there was a significant improvement in poverty. Poverty was less prevalent in farm households where there were higher rates of MV adoption.

However, it is believed that agricultural R&D improves agricultural productivity, which increases income and thus reduces poverty. Movements of rice yield and poverty level trends are analyzed using available time-series data on Thailand at the regional and national level. Due to the limited time-series data on the percentage of people living under the poverty line in Thailand, Table 6.5 shows the time series for 12 years at the national level and 6 years at the regional level. The available data is based on the normal consumption pattern of the Thai population. The poverty line is defined as the minimum income needed to acquire the minimum diet considered adequate (Sen 1981; Hossain and Sen 1992). Poverty lines were estimated by the World Bank in 1962 and modified in 1980 (World Bank, 1980).

The socio-economic censuses conducted by the National Economic and Social Development Board of Thailand (NESDB) in 1996 and 1998 are also used to estimate the percentage of people living in poverty in each province. The rice yields of 74 provinces in 1996 and 1998, reported in Agricultural Statistics of Thailand Crop Year 1998/99 by the Office of Agricultural Economics (OAE), are used to test the relationships between rice yield and poverty. In addition, the data in 1996 and 1998 are pooled into one group, and are used to test the relationship. The detailed data in each province both in 1996 and 1998 are shown in Appendix A.

Time series data of rice yields and the percentage of the people living in poverty at the regional and national level are used to estimate the relationship. The percentage of people living below the poverty line, reported in Table 6.5, is estimated from many sources. Meesuk estimated the data from 1962/63 to 1975/76 in " Income, Consumption and Poverty in Thailand, 1962/63 to 1975/76", while the data in 1981 and 1986 are estimated by the Science and Technology Development Board (STDB). The data since 1988 has been estimated by the National Economic and Social Development Board (NESDB) under the supervision of Asian Development Bank (ADB). Regional data from four regions throughout the country since 1988 are also presented in Table 6.5. The percentage of people living under the poverty line decreased over the period up until 1996, when it increased from 11.4 percent in 1996 to 13.0 percent in 1998, and then increased again to 15.9 percent in 1999 because of an economic crisis (NESDB, 2000).

Table 6.6 shows the average growth rate of rice yield for the whole kingdom and each region between 1962/63 to 1999 and 1988 to 1999 respectively. The average growth rate of rice yield increased at 1.05 percent per annum over this period, while the average rate of the percentage of people living in poverty decreased, at 4.15 percent per annum. This phenomenon occurred in every region of the country. Moreover, the percentage of people living in poverty is much higher in the northeastern region, where rice yields are lowest. Similarly, the levels of poverty in the central region are the lowest while the rice yields are the highest. Figure 6.2 and 6.3 shows the trend lines of poverty moving in the opposite direction of the level of rice yield for the whole kingdom and each region. This indicates that the increase of rice yield may directly and indirectly help to lower the percentage of people living in poverty throughout the country

Table 6.5 Rice Yield and Percentage of People under Poverty Line in Thailand

Year	Whole Kingdom							
	Yield (kg/rai)				Percent Poor			
1962/63	256				57.0			
1968/69	296				39.0			
1975/76	295				31.0			
1981	312				23.0			
1986	328				29.5			
1988	343				32.6			
1990	313				27.2			
1992	348				23.2			
1994	376				16.3			
1996	386				11.4			
1998	364				13.0			
1999	372				15.9			
Region								
	Northeast		North		Central		South	
	Yield	%Poor	Yield	%Poor	Yield	%Poor	Yield	%Poor
1988	235	48.4	413	32.0	421	26.6	304	32.5
1990	263	43.1	448	23.2	392	22.3	281	27.6
1992	281	39.9	453	22.6	461	13.3	309	19.7
1994	270	28.6	420	13.2	475	9.2	332	17.3
1996	289	19.4	499	11.2	516	6.3	322	11.5
1998	283	24.0	451	9.1	505	7.6	353	14.6
1999	280	30.8	462	10.6	556	7.5	350	15.7

Source: NESDB (2000)

Thailand has been traditionally divided into four major regions: Northeast, North, Central Plain, and South. The Central Plain is the nation's most productive region for rice as it has the highest rice yields. Table 6.6 shows that the average rice yield in the Central Plain region between 1988 and 1999 was the highest level at 475 kg/rai. The average rice yield in this region also had the highest growth rate of 3.11 percent per annum. The highest decreasing rate of poverty at 15.76 percent per annum in the region also occurred during this period. The Northern region was second to the Central Plain with an average rice yield of 449 kg/rai between 1988 and 1999. This was also associated with a large decreasing rate of poverty at 12.65 per cent per annum, second to the Central Plain.

In contrast, the Northeastern region of Thailand is the poorest in terms of soil fertility and water control, resulting in the lowest rice yields per unit area in the country at only 272 kg/rai between 1988 and 1999. Although the growth rate of rice yield increase is higher than rice yield increase in the Northern region, the rate of poverty reduction in the region is lower. The Southern region of Thailand has the smallest area under rice cultivation in the country. In this region the average rice yield per unit area is lower than in the Central Plain and the Northern region, but higher than in the Northeastern region. In the same period, increased growth in average rice yield is associated with a decreasing rate of poverty at 8.94 percent per annum, which is lower than in the Central Plain and Northern region, but higher than in the Northeastern region.

The above relationship between rice yields and poverty levels in each region indicate that the percentage of people living in poverty has decreased more rapidly in the regions which have high rice yields than in regions which have low yields. This indicates that the higher the yields the larger the decrease in the poverty level. Moreover, the decreasing growth rate of poverty in each region (except in the

Northern region) is associated with an increasing growth rate of rice yields. This can also be observed in Figure 6.2 and 6.3 which show the poverty trend lines moving in the opposite direction to the level of rice yield for the whole kingdom and each region. This indicates that the increase of rice yield may directly and indirectly help to lower the percentage of people living in poverty throughout the country. In order to confirm this relationship, the relevant data are tested using regression analysis.

Table 6.6: Growth Rates of Rice Yield and Poverty Level by Whole Kingdom and Regions

Region	Average Yield (kg/rai)	Growth Rate (%)	
		Yield	Percent Poor
North-East*	271.57	1.50	-7.17
North*	449.00	1.00	-12.65
Central*	475.00	3.11	-15.76
South*	321.57	1.97	-8.94
Whole Kingdom**	332.42	1.05	-4.15

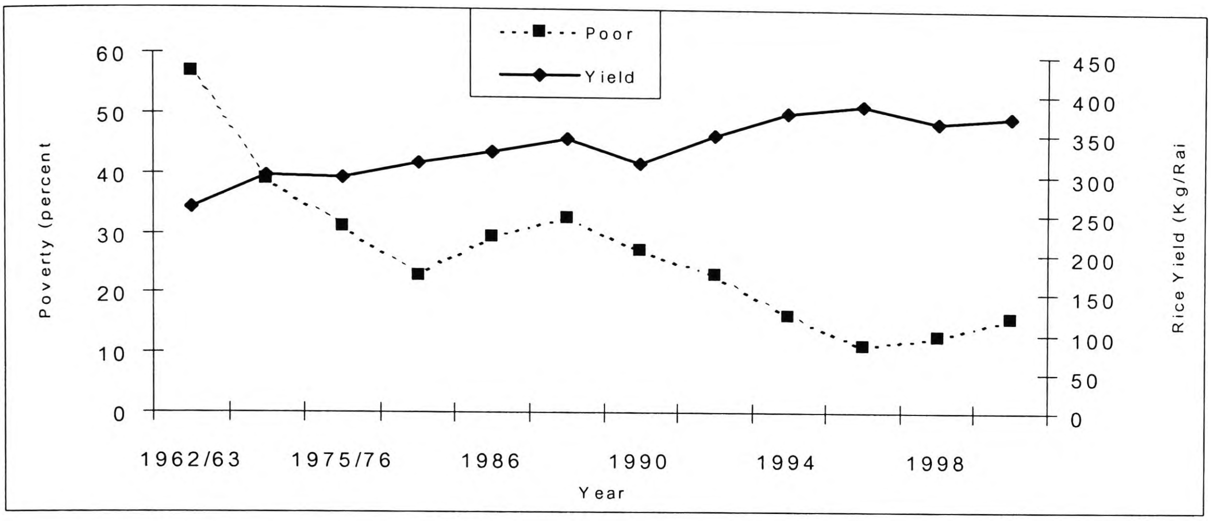
Source: Calculated from the data in Table 6.5

Notes:1) The growth rate are computed by semi-log method.

2) All computed growth rates are statistically significant at the 5 percent level.

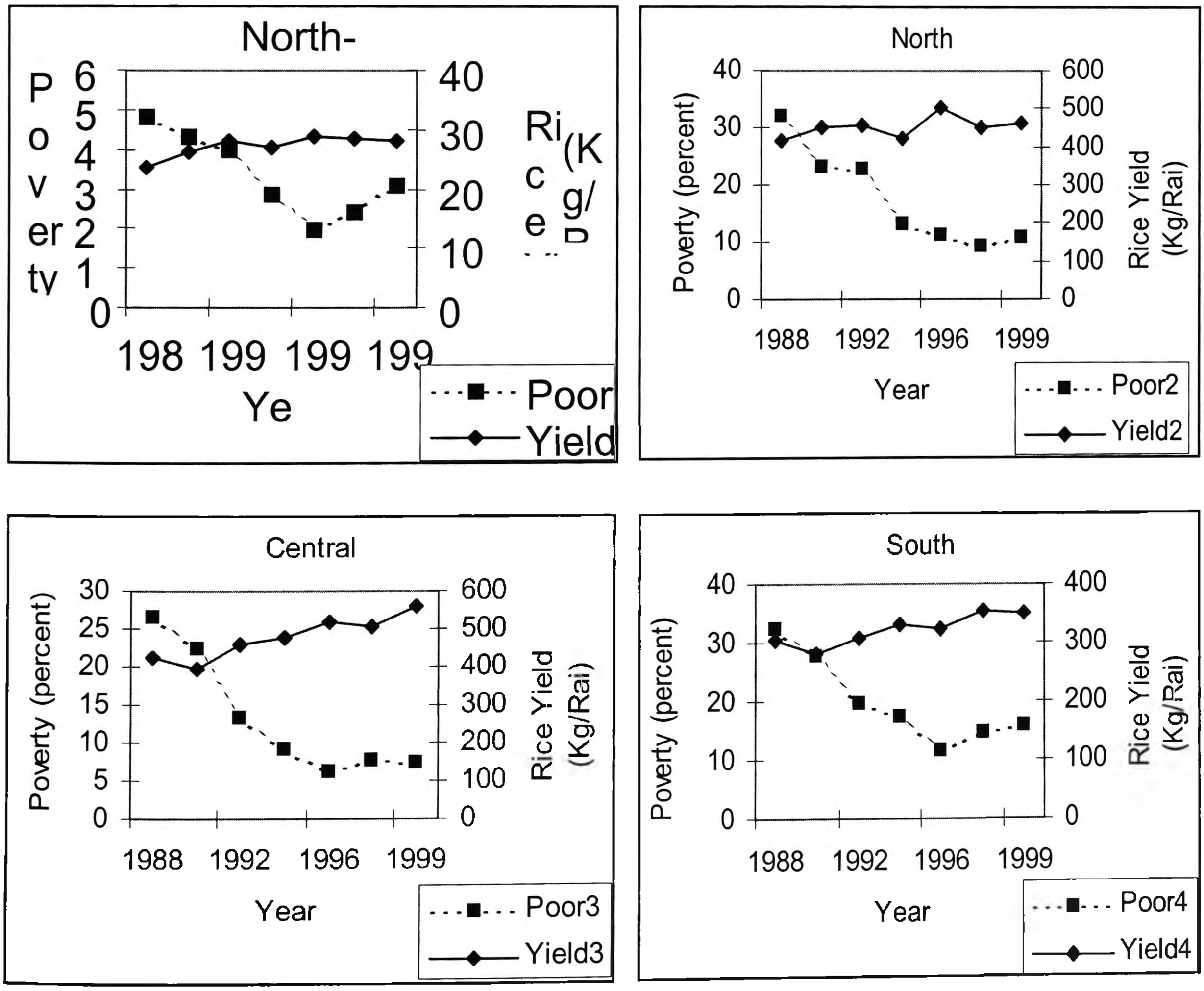
3) * data from 1988 to1999, ** data from 1962/63 to 1999

Figure 6.2: Rice Yields and Poverty Level in Thailand 1962/63-1999



Source: Table 7.5

Figure 6.3: Rice Yields and Poverty Level in Each Region in Thailand 1988-1998



Source: Table 6.5

The estimating equation function of poverty level as a dependent variable and rice yield as an explanatory variable is expressed in double natural logarithm form. The OLS method is used to estimate the model. The estimated adjusted coefficients of determination (R-bar-squared), and t-test results are presented in Table 6.7. The results of the provincial data set for 1996 show that although the compatibility of the models, as indicated by the R-bar squared, is not high, all of the explanatory variable efficients in each model are highly significant with expected signs. The relationships between rice yields and the poverty levels in Thailand in 1996 are negative and significant at the one per cent level, but the appropriateness of the model is low with the R-bar-squared at 0.14. This suggests that there are a number of other important factors affecting poverty. Similarly, the negative relationship between rice yields and poverty levels for 1998 data is statistically significant at the one percent level, and the R-bar-squared is 0.32. This, again, emphasises that other important variables besides rice yield reduce poverty. Rice yield elasticities for poverty level are 1.37 in 1996 and 2.07 in 1998, meaning if rice yield increased by 1 percent, the poverty level would decrease by 1.37 and 2.07 percent respectively. When the two sets of cross-provincial data are pooled, the results of statistical test confirm a negative relationship between rice yields and the poverty level which is statistically significant at the one per cent level. The estimated coefficient function with 1996 and 1998 cross-sectional data sets is not statistically different from each other. This indicates that policies to increase rice yield play an important role in the reduction of poverty in Thailand.

Table 6.7 Relationships between Rice Yield and Poverty Level (Cross-sectional Provincial Data)

Relationships	No. of Observation	Coefficients	R-Square
1.Cross-sectional provincial Data 1996	74	-1.37 (-3.40)**	0.14
2.Cross-sectional provincial Data 1998	74	-2.07 (-5.75)**	0.32
3. Pooled provincial Data (1996 and 1998)	148	-1.68 (-6.18)**	0.20

Source: Appendix G

Notes: 1. Log linear model estimated using the OLS method

2. Figures in parentheses are t-statistics

3. ** are significant at the 1% level

Moreover, the comparison of the results to earlier estimates of provincial data, and time series data between 1988 and 1999 based upon the report of NESDB (2000) are used to estimate the relationship between rice yields and the percentage of people living in poverty. The results are presented in Table 6.8. Unsurprisingly, the rice yield elasticity of poverty level is highly significant at the one per cent level. The R-square was at 0.52, which is higher than the results of early estimations with cross-provincial data.

However, when 12 year time-series data at the national level based on the report of NESDB (2000) is used in the regression analysis, the estimated equation provides an estimated rice yield elasticity with respect to poverty of 3.48 which is significant at the one percent level. The R-bar-square is high at 0.79, and t-test results are satisfactory.

Table 6.8 Relationships between Rice Yield and Poverty Level (Cross-sectional Regional and Time Series Data)

Relationships	No. of Observation	Coefficients	R-bar-Square
1.Cross-section Regional Data	28	1.75 (-6.22)**	0.58
2. Time Series Data	12	-3.48 (-6.56)**	0.79

Sources: Appendix G

Notes: 1. Log linear model estimated with the OLS method

2. Figures in parentheses are the t-statistics

3. ** are significant at the 1% level

Although cross-sectional data (provincial and regional data sets) and time series data are used to estimate the equation for the poverty level, the results from both data are consistent. All equations show a statistically significant negative relationship between the poverty level and rice yield. However, the high rice yield elasticity is derived from only 12 years of data, and as such this may result in biased estimators because of the small number of observations. The appropriate estimators should range from 1.37 to 2.07, measuring if rice yield increases by 1 percent, the poverty level will decrease between 1.37 and 2.07 percent.

The above results indicate that the poverty level in Thailand can be partially reduced by increasing the yield of rice. This relationship between poverty levels and rice yields also indicate that a high rice yield level has a greater impact on the reduction of poverty than a lower rice yield level. As R&D is an important determinant of rice yield, it can help to alleviate poverty in the country through increasing the yield of rice.

6.4 Conclusion

The rates of return to R&D investments are calculated with standard formulae by two approaches: the traditional approach and the stock approach with a depreciation rate. Using time-series data of R&D expenditures both between 1950 and 1998, and between 1967 and 1998, the Almond technique approach fails to capture the lag structure. However, when time-series data of R&D knowledge stock between 1950 and 1998 is used, the second-degree polynomial of Almond technique is able to capture a lag structure of 8-years represented in an inverted-U-shaped lag. The rate of return to R&D investment is 44.54 percent per annum.

This study proposes a new approach - the stock approach with depreciation rates - to calculate the rates of return to R&D investment by using R&D knowledge stock as a research variable in the rice yield function. Lag structures determined by the concept of depreciation rate of capital stock are used. The study shows that if R&D knowledge stock does not depreciate, the rate of return to rice R&D investment is 17.93 percent per annum. This rate of return is high, and an attractive return for an investment of this nature. If R&D knowledge stock depreciates by five percent per annum, the rate of return increases to 25.72 percent and if it depreciates by ten per cent per annum the rate of return increases again to 36.42 percent per annum. These rates of return are also high and attractive for this kind of investment. However, the results of MIRR estimation using both the traditional and stock approach show that investment to stimulate rice yield growth provides the high returns. This indicates that rice R&D investment in Thailand is under-funded.

Cross-provincial data, regional data and time series data are used to investigate the relationship between rice yields and the percentage of people living in poverty. The results show that there is a negative relationship between rice yield and the level of poverty which is statistically significant at the one percent level. The proportion of people who are below the poverty line has fallen significantly as rice yields have increased. However, the results suggest that there are a number of other important factors which affect the poverty level. Rice yield is able to stimulate wider growth in both farm and non-farm economies, which in turn helps to alleviate poverty. However to ensure the poverty level falls, productivity growth needs to be supported by other policies such as special government programs that target those below the subsistence level. As R&D plays an important role in increasing rice yield, this implies that rice R&D can help to alleviate poverty in Thailand as initially hypothesised.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATION

In this chapter, a summary of the study will be provided, and conclusions are drawn. Finally, policy implications and suggestions for future studies are addressed.

7.1 Recapitulation, Discussion and Conclusion

The average rice yield in Thailand decreased from the 1910's until the mid 1950's when it stagnated. Since the 1960's, rice productivity has fluctuated and increased continuously until the present day. Thailand has achieved self-sufficiency and has become a major rice exporter in the world market due to the remarkable performance of its rice production over the past 30 years. Eighty percent of production growth in the first period (1967-1976) was due to area expansion while yield increases accounted for 20 percent of the growth. However, increases in yield became the dominant source of rice production growth in the second period (1977-1986) and the third period (1987-1998) accounting for about 65 and 88 percent of the growth respectively. This increase in rice yield is mainly due to the enormous investment in irrigation, the effort made in R&D for rice, and the pervasive use of chemical fertilizers in rice fields driven by the Thai government.

However, Thailand's rice yield is very low when compared to other countries in the world. Moreover, there is the evidence that the gap between the world's rice yield and Thailand's rice yield has been widening over time. This has led to higher unit costs of production when compared to other major rice-growing countries. Consequently, Thailand's position as rice export leader in the world rice market has declined during the 1992-1995 period. It has been suggested that the low rice yield in Thailand may be due to insufficient investment in R&D. Thus, this study investigated whether R&D is a determinant of rice yield growth, and if so, whether R&D funds in rice are appropriately allocated.

The purpose of this study is to examine the relationships between rice yield and the determining variables, to calculate the rate of return to rice R&D investment, and to investigate the relationships between rice yield, income and poverty alleviation. If these relationships are well established and stable, the promotion of agricultural R&D activity will increase rice productivity, increasing income and reducing poverty in the country.

Previous studies on the contribution of R&D to agricultural output and productivity were generally conducted using three approaches: the economic surplus approach, the cost-benefit analysis approach, and the econometric approach. In this study, the cointegration approach with the Johansen procedure is applied as this approach eliminates the spurious regression generated from the OLS technique when non-stationary time-series data is used.

To achieve the purpose of this study, the concept and procedure used to estimate the R&D coefficients, and to calculate the rate of return to R&D investment, including the sources of data were presented. An overview of the production economy of Thai rice and agricultural R&D system in Thailand was presented as a background to this study, including a preliminary survey on the relationship between rice productivity and the determining inputs.

In accordance with the cointegration approach, the unit root test was used to investigate whether the time series data in the model was stationary. Then the cointegration approach with the Johansen approach was applied to test whether the time series data was cointegrated. The determinants of the rice yield response function were then estimated by the OLS method, and the MIRR was calculated using the research elasticities of rice yields. Finally, the conclusions are drawn, then the policy implications and suggestions for future study are discussed.

There are three major findings of this study: the sources of rice yield, the rate of return to R&D investment, and the effect of an increase in rice yield. These three results can be used as indicators to evaluate the level of R&D investment and the contribution of R&D investment to agricultural productivity in Thailand.

7.1.1 The Relationship between Rice Yield and Determining Inputs

To investigate the factors affecting rice yield, the yield response function was used as an empirical study. This function is transformed from a Cobb-Douglas production function by dividing both sides of the function with hectarage. The rice yield response function is assumed to take a natural logarithm linear form. Moreover, the fertilizer response function is assumed to form a recursive system of rice yield response function.

All time-series data within the empirical models that are used to test the long-run relationship between rice yield, chemical fertilizer use, irrigated area, and R&D expenditure, R&D knowledge stock, and hectarage, are non-stationary in the level but stationary in the first, second, and third difference. The cointegration approach is then used to test whether the time-series data are cointegrated. If the time-series data are cointegrated, it suggests that there is a long-run or equilibrium, relationship between them.

Using a vector autoregressive (VAR) model with the Johansen procedure, the estimated rice yield response equations show that rice yield, chemical fertilizer, irrigation, current R&D expenditure, R&D knowledge stock, and hectarage are cointegrated. The relationship equation is then established. This implies a long-term relationship between rice yield and the expected determining inputs. When the OLS method is applied to estimate the rice yield response function and statistically test a significant level of estimated coefficients, it found that there are three models. A model consisting of chemical fertilizer, R&D expenditure, hectarage, a model using irrigated area, R&D expenditure, hectarage, and a model using R&D expenditure, R&D knowledge stock, and hectarage are the feasible regression equations to be used to estimate the shares of determining inputs in rice yield. Moreover, the estimated fertilizer response equations indicate that irrigation, current R&D expenditure, R&D knowledge stock, and hectarage induce greater fertilizer application. These relationships indicate that chemical fertilizer, irrigation, current R&D expenditure, R&D knowledge stock, and hectarage are complementary in rice production. However, the model consisting of R&D expenditure, R&D knowledge stock, and hectarage is the most suitable in estimating the rate of return from R&D. In order to test the direction of the relationships, the Granger causality test is applied. The results show that R&D expenditure and R&D knowledge stock are Granger prior to rice yield and vice versa, supporting the cointegration test results.

To account for the separate contribution of each determining input to rice yield, the elasticities of rice yield with respect to each input are calculated from the results of the OLS method. If chemical fertilizer use increases by 1 percent, rice yield will rise by 0.06 percent. If irrigated area increases by 1 percent, rice yield will increase by 0.13 percent. Current R&D expenditure and R&D knowledge stock are important determinants of rice yield in all estimated equations. If current R&D expenditure increases by 1 percent, rice yield will arise by 0.10 percent. If R&D knowledge stock increases by 1 percent, rice yield will increase by 0.20 percent. However, hectarage (rice land) still remains as important determinant of rice yield. The above results may imply that chemical fertilizer, irrigated area, current R&D expenditure, R&D knowledge stock, and hectarage are complementary in rice production, and the resulting multicollinearity problem does not allow one model to capture the determinants of rice yield.

There are many factors determining rice yield growth and rice yield variability reported in several studies including Bickel (1976) and Isvilanonda and Poapongsakorn (1995). The factors influencing rice yield variability were classified into five major groups: traditional factor of production (land, labour, capital, fertilizer, and farm machinery), natural factors (weather and soil), economic factors (price and income), technological factors (literacy rate, R&D, extension), and institutional factors (irrigation, road, and government policy). However, some of those factors do not significantly increase rice yield or do not have a large impact on rice yield and production. Moreover, there is evidence from many countries in Asia that most of the increased rice production in the 1960's and the 1970's was due to higher rice yields resulting from the adoption of high-yielding modern varieties together with improved farming practices, and the expansion of irrigation and chemical fertilizer use. Thus, in this study, the main factors determining rice yield growth are the expansion of irrigated area, chemical fertilizer usage, current R&D expenditure, R&D knowledge stock, and hectarage. The other factors are classified as the supporting factors. R&D activities produce and improve knowledge and materials such as MVs and new techniques, which are used directly in production, while fertilizer and irrigation are the complementary factors to be used in the production process. It is well known that the green revolution in rice cultivation was most successful in irrigated areas with MVs and pervasive chemical fertilizer use. The MVs were bred to be highly responsive to good water control and chemical fertilizer use. As such, it is not surprising that these inputs are the major determinant of rice yield growth in Thailand, as hypothesised in this study.

In conclusion, investment in rice R&D, chemical fertilizer use, and irrigated area expansion, are the major factors affecting rice yield growth. Fertilizer, irrigation, and R&D investment are complementary to each other and should be implemented as a package of technology to enhance rice yield in Thailand. Agricultural R&D knowledge stock is an appropriate R&D variable to be used to explain the rice yield growth and to calculate the rate of return to R&D investment. This R&D knowledge stock changes over time as agricultural knowledge is accumulated and embodied in organisations, agricultural scientists and farmers, documents, new varieties of rice, new devices, new techniques, and so on. Old knowledge can be also used to generate new knowledge. The continuous change of productivity over time should be attributed to R&D knowledge stock rather than current R&D expenditure. This may be able to explain why rice productivity has been increasing while the R&D expenditure for rice has been decreasing. However, this knowledge stock may also depreciate over time as knowledge becomes obsolete and is replaced by new knowledge generated from R&D activities.

7.1.2 The Rates of Return to R&D Investment

The MIRR for R&D investment is calculated with standard formulae, by two approaches: the conventional approach and stock of knowledge with depreciation approach. With the conventional approach, the rate of return to R&D investment is calculated by using the estimated distributed lag coefficients of R&D knowledge stock, obtained from the Almond lag technique. The rate of return to R&D investment calculated by this approach is high at 44.54 percent per annum. Similarly, when the R&D knowledge stock incorporating depreciation is applied, the elasticities of rice yield with respect to R&D knowledge stock with a zero, five, and ten percent depreciation rate generate significant positive results. This indicates that the flow of benefits from R&D are positive. If R&D knowledge stock does not depreciate, the rate of return to rice R&D investment is 17.93 percent per annum. This rate of return is considered a high and attractive return for an investment of this nature. If R&D knowledge stock depreciates by five percent per annum, the rate of return increases to 25.72, and if the depreciation rate is 10 percent per annum, the return increases again to 36.42 percent per annum. However, the results of the MIRR estimation using both traditional and stock approach show that rice R&D investment to stimulate rice yield growth provides the high returns. This indicates that rice R&D investment in Thailand is under-investment as hypothesised in this study.

Although there are many approaches used to calculate the returns to investment in agricultural research, neither approach is superior in all situations as discussed by Martin (1977), Lindner and Jarvett (1978), Fox (1985), Norton *et al* (1987) and Harvey (1988). In the production function approach, R&D variables and lag structures are considered crucial in determining the stream of benefits and the rate of return from R&D investment. In the literature, R&D variables are classified into two groups: input side variables of which R&D expenditure is used as a proxy, and output side variables of which R&D knowledge stock or other research outputs are used as a proxy. However, the major source of variation among production function studies is the time lag structure of research reflecting the contribution of R&D investment to production or productivity. The length and shape of the lag structure remains controversial and there is a need for future research in this area.

In this study, R&D knowledge stock is the accumulation of R&D expenditures in the past, and this is based upon the concept that R&D results or outputs are generated from the accumulation of knowledge from basic research, applied research and development (presented in Chapter 4). Moreover, this knowledge stock is embodied in people (agricultural scientists and their staff), R&D organization, publications, and so on. It is also assumed that existing R&D knowledge stock is issued in the form of new or improved outputs, inputs, or farming techniques, and these technologies can be immediately applied to agricultural practices.

Moreover, with the stock approach incorporating depreciation, a change in one unit of R&D investment impacts on production or productivity over many years until this R&D knowledge stock becomes obsolescent. There is a stream of benefits occurring over time as a declining proportion corresponding with the period of depreciation. Therefore there is a dynamic relationship between currently existing research knowledge and production or productivity in the future. In this approach, the lag shape is simply constructed as a right-angled triangle following the straight line depreciation rate, and the lag length is the period of depreciation. The stream of benefits from one unit of R&D knowledge gradually decline along the period of depreciation of such knowledge.

Using R&D knowledge stock with depreciation instead of R&D expenditure with specific time lag structure to evaluate the rate of return to R&D investment is relevant to the nature of agricultural R&D knowledge in three ways. Firstly, R&D knowledge stock can be accumulated and embodied in human, R&D institutions, and so on. The mechanism of knowledge accumulation is a continuous process. Pre-existing knowledge often becomes the precursor to new knowledge. Secondly, agricultural R&D knowledge stock can change over time. Not only can it be accumulated, but it can also become obsolete. Thirdly, the contribution of agricultural R&D knowledge to production or productivity has a lag time. However, the lag period should occur in the process of technology adoption, not in the knowledge production process. Existing knowledge such as new techniques in farming cultivation, high-yield seeds, and so on, were generated from R&D activities and should be used in agricultural production without a time lag.

In conclusion, although rice R&D played important role in the increase of rice yield in Thailand during 1967-1998, investment in R&D was still low. The contribution of R&D investment to rice productivity show that the return to R&D investment provides high rates of return. Agricultural R&D knowledge stock can be used to explain productivity rather than R&D expenditure with specific or restricted time lag. Moreover, previous polices for rice R&D in Thailand have focused on improvements in rice quality rather than on increasing productivity, which may explain why Thai rice yields are very low when compared to other countries.

7.1.3 The Implication of Rice Yield for Income and Poverty Alleviation

The most important task of agricultural R&D is to improve the living standards of the poor. Agricultural R&D is vital in helping increase food production and alleviate famine throughout the developing world. However, many people question the role of agricultural R&D in raising farm incomes and alleviating poverty. Therefore, the relationships between rice yield, incomes, and the poverty level have been investigated. Policy makers should be concerned with the impact of agricultural R&D investment on increasing incomes and reducing poverty.

The results show that rice yields have a positive relationships with non-farm and farm incomes and have a negative impact on the poverty level. The impact of rice R&D on raising income and alleviating poverty are evident through its effect on rice yield. The percentage of poor people is calculated from the number of people living below the poverty line. Agricultural productivity growth can stimulate wider growth in the farm and non-farm rural economy, which in turn can contribute to poverty alleviation. However, the levels of poverty also depend on other factors and favourable conditions. Thus, enhancing rice yield growth white targeting the poor requires special programs support.

An increase in rice yield or agricultural productivity can impact income and the poverty level both directly and indirectly. Increases in agricultural production and productivity resulting from R&D-led technological change helps to eliminate famine for poor people who spend the most their income on food. Nutritional status will improve as sufficient caloric intake (poverty level is measured as insufficient calories intake) is achieved from increased agricultural productivity. Moreover, increases in agricultural productivity have created more employment, and cheaper and more abundant food in both the rural and non-rural economy. This should lead to higher farm profits, higher wages, and consequentially higher incomes in the farm and non-farm economy. However, the expansion of agricultural production is expected to generate lower prices. Farmers incomes may drop and net incomes may decline if production unit costs fall to less than output prices. However, the increase of agricultural productivity of rice, the most important crop for poorer countries, will help to reduce the price and increase its availability.

The impact of yield improvement on income and poverty alleviation depends on certain conditions. Increasing the yield of rice requires support from programs such as government services and accessibility of infrastructures. If agricultural yield improvement is combined with other favorable government policies targeted at the poor, agricultural R&D will play an important role in increasing income and alleviating poverty.

In conclusion, rice R&D plays an important role in raising both farm and non-farm incomes and reducing poverty through the increase of rice yields. Increasing rice R&D will result in a significant rise in household and per capita income thereby there by significantly reducing poverty in Thailand. Rice R&D promotion is a favorable policy for Thailand to increase income and alleviate poverty in the country.

7.2 Policy Implications

Although the rice area, rice production and rice yield in Thailand has increased over the last four decades, Thailand's share in the world rice production economy, trade, and yield has declined. Thailand's position in the global rice production and trade has fallen since the 1980's. The slow growth in rice yield in Thailand and the ever-widening gap between the Thai and the global rice yields bring about many problems. Firstly, the unit cost of rice production in Thailand has increased. Consequently, Thailand has gradually lost its competitive advantage in rice production. Secondly, the real world and domestic rice prices have declined, Thai farmers have had to gradually decrease their rice production or change to other crops as the profitability declines. Consequently, Thailand has gradually lost its position as a leading rice exporter in the world market because of its inability to produce more rice at internationally competitive prices.

Moreover, there is some evidence that Thailand under utilises input uses and R&D investment in the rice sub-sector when compared to other countries which have similar agro-climate conditions and land endowments. These factors were also found to be positively associated with the levels of rice yields in each country. The strong positive association between rice yield and major input uses, such as modern varieties, chemical fertilizers, and irrigation, and R&D investment are significant.

A diminishing trend in rice yield, in addition to Thailand's recent changes in environmental degradation and soil fertility have occurred, and as such Thailand requires an appropriate policy to increase or even to sustain the growth of rice yields. Table 7.1 presents data from two sources on irrigated yields, rainfed yields, national average yields, and experimental station yields in Thailand in 1990 and 1995. The data shows the percentage gap between potential yield indicating an opportunity to develop rice yield. In 1990, the percentage gap between potential yield and current yield for irrigated rice was high at 80 percent (from 2,500 kg/ha to 4,500 kg/ha) and was 39 percent for rainfed rice (from 1,800 kg/ha to 2,500 kg/ha). Moreover, according to the data from Dey and Hossain (1995), the percentage gap between average potential rice yields and current national average yields was high at 165 percent (from 2,000 kg/ha to 5300 kg/ha). This indicates that there is a large opportunity to increase rice yields through both irrigated rice and rainfed rice. Farmer's rice yields are far from approaching the potential attained in experimental stations. Therefore, it is highly feasible that increased technological knowledge and innovative policy options will lead to increase rice yields in Thailand.

Table 7.1 Actual and Potential Yields in Thailand (kg/ha)

Types of Cultivated Area	Actual Yield	Potential Yield	Difference
Irrigated Rice*	2,500	4,500	2,000
Rainfed Rice*	1,800	2,500	700
National Average Rice**	2,000	5,300	2,300
Irrigated Rice**	4,000	-	-

Sources: * Hirsch (1990:17)
**Dey and Hossain (1995)

At present, Thailand remains the leader of rice-exporters in the world market; however, a very low rice yield may cause Thailand to lose this position in the future due to the high increase of unit production costs and a declining export surplus (Isvilanonda and Poapongsakorn, 1995: 118). The profitability of rice production can only be sustained if unit costs of production continue to remain below the output price. Generally, maintaining and decreasing unit costs of production and accelerating export surplus can be achieved through a shift in the yield per hectare and/or through increasing the efficiency of inputs used.

In order to increase rice yield growth in Thailand, proper policy measures should be implemented to turn the potential into reality. The Thai government should formulate and put in place policies favorable for rice production. Thus, fertilizer use, irrigation, and R&D activities, should be promoted as they are the most effective factors to accelerate rice productivity.

As it is likely there will be limitation on chemical fertilizer use and the expansion of irrigated areas in the future, a feasible way for Thailand to maintain and raise the rice yield growth in the future is to increase R&D funds and to improve the R&D organization by modernising the knowledge base or knowledge stock and increasing the efficiency of fertiliser use and water management concurrently. New rice varieties should also be encouraged to enhance rice yield growth as well as rice-quality improvement. In this area, biotechnology and/or genetic engineering has the potential to improve breeding high-yielding cultivars with high quality grain and resistance to major insects and diseases.

In rainfed areas and areas of problem soil where the average rice yields are very low due to the constraint of irrigation and fertilizer use, scientific advances in biotechnology should focus on new varieties which are capable of withstanding moisture stress, and fluctuations in soil acidity and salinity. Therefore, R&D in rice in Thailand should be aimed at engineering high-yielding cultivars, developing rice varieties with broad-based genetic compositions whose yields are less sensitive to irrigation and fertilizers.

Conversely, for favorable planted areas (irrigated areas and rainfed lowland areas), R&D outcomes involving both technology and management practice should be applied in conjunction with increased fertilizer use and irrigation improvement. To avoid damage to the environment and the high costs of increased chemical fertilizer, organic fertilizer improvement of land use such as land consolidation, and the promotion of ecosystem farming together with water management should be encouraged.

Similarly, the lack of water available for irrigated agriculture is a very serious concern. The quantity and quality of water available for rice growing is expected to decline because of high developmental costs and environmental concerns. The only solution is to improve the efficiency of water management and control at both the national and farm level. Other factors influencing rice productivity growth such as rural infrastructure and mechanisation should be recognised.

In order to maintain and increase rice productivity growth in Thailand, R&D funding should be increased immediately in addition to improved efficiency in irrigation and fertilizer use. Public investment in rice R&D should be increased, both in absolute terms and relative to investment in other publicly financed projects, due to the positive impact this has on economic development. R&D in rice should focus on increasing high-yield and high quality rice research, support knowledge-intensive farming to improve the efficiency of input use, particularly fertilizer and water. The new technology derived from R&D should be complemented by appropriate policies to improve water management, land fertility, and to increase the efficiency of fertilizer use to ensure an increase in rice yield in the long term. The cultivars improvement and modern technologies should be more focused on the irrigated and rainfed lowland areas which have potential to increase rice yield.

However, it is important to note that the policies to improve input efficiency and reduce unit costs of production depend not only on rice R&D but also other socioeconomic and institutional factors. According to ADB (2000), Kerr and Kolavalli (1999), and Pingali *et al* (1997), improving the efficiency of rural infrastructure, sustaining natural resources in farms, increasing farmers' knowledge and skills, as well as expanding the reach of social safety-net programs are necessary to support efforts to increase future rice yields in Asia.

Therefore, there are four aspects required to achieve an increase in rice yield growth in Thailand over the long period. Firstly, R&D activities in rice should be strongly supported and improved to overcome the constraint of high-yield with high-quality rice in the country. Secondly, the efficiency and management of irrigation and fertilizer use should be improved. Policies to increase soil fertility and promote efficient water control should be under taken. Thirdly, high-yield gains in irrigated areas and favorable rainfed areas will be the first priority for yield improvement. Finally, the favorable socioeconomic and institutional factors should be invoked to co-ordinate policies with rice R&D promotion.

7.3 Suggestions for Future Study

They are several weaknesses in this study which should be overcome in future studies. Firstly, the calculation of the return of R&D investment with this approach should be used to compare different kind of crops or in the aggregate level. This research dealt with only partial productivity of rice crops that measured the change in land productivity (yield) alone. It cannot reflect the total productivity contributed from all inputs. Other inputs such as labour and capital may also influence rice yield. Total factor productivity (TFP) should also be undertaken in the future study when other relevant inputs can be obtained.

Secondly, we used R&D knowledge stock instead of R&D expenditure in this study because the certain shape and lag length of R&D expenditure remains controversial. This study provides evidence showing that R&D expenditures on rice was drastically cut when the Department of Rice became a division under the Department of Agriculture in 1972. After 1972, the R&D budgets increased slightly while rice yield growth continuously rose. This may be due to the momentum of R&D knowledge stock accumulated from past investments in R&D. Thus the rice R&D knowledge stock should be used to explain the change of rice productivity rather than R&D expenditures. However, the R&D knowledge stock calculated from the accumulated R&D expenditures since 1950 with depreciation rates was used rather than the traditional R&D expenditure, to calculate R&D return. We ignored the R&D investments prior 1950 because of data limitations. This may have under-estimated the stock of R&D knowledge. Moreover, we assumed that R&D knowledge stock has a constant rate of depreciation. The reason for this is that the exact depreciation rate of R&D knowledge stock and its profile is not known. Future studies should measure the knowledge stock by other proxies such as the number of patents, documents, and research work. R&D depreciation as an alternative for a time lag profile of R&D variables also requires greater attention.

Thirdly, a large gap of 39 percent to 165 percent between potential (research station) and actual yields has been identified. In this context, investment in agricultural extension (technology transfer) may be priority over other aspects of agricultural R&D, which should be empirically verified further in the future research.

Finally, when studying the impact of rice yield on the poverty level, we could only attain the relevant time-series data for 12 years. This is a small number of observations, which may have led to biased estimators. Cross-sectional data at provincial, regional, or international levels is necessary to investigate this relationship.

APPENDIXES

APPENDIX A: DATA

Table A.1: Rice Harvested Area, Production and Yield of the World and Thailand, 1961-1999

Year	World			Thailand		
	Production (1000Mt)	Harvested Area (1000Ha)	Yield (Kg/Ha)	Production (Mt)	Harvested Area (1000 Ha)	Yield (Kg/Ha)
1961	215,655	115,501	1,867	10,150	6,120	1,659
1962	226,555	119,582	1,895	11,250	6,540	1,720
1963	247,140	120,277	2,055	12,171	6,500	1,873
1964	263,019	125,218	2,101	11,600	6,310	1,838
1965	254,081	124,985	2,033	11,164	6,270	1,781
1966	254,828	125,871	2,025	13,500	6,830	1,977
1967	277,488	128,928	2,152	11,198	6,100	1,836
1968	284,729	131,191	2,170	12,410	6,500	1,909
1969	293,485	133,574	2,197	13,410	6,935	1,934
1970	308,767	134,394	2,297	13,270	6,727	1,973
1971	306,382	133,634	2,293	13,744	7,096	1,937
1972	292,716	129,981	2,252	11,669	6,571	1,776
1973	323,163	135,490	2,365	14,898	7,143	1,924
1974	321,040	135,817	2,364	13,386	7,333	1,825
1975	359,693	142,668	2,521	15,300	8,383	1,825
1976	350,171	142,807	2,452	15,068	8,320	1,811
1977	369,729	144,448	2,559	13,921	7,947	1,752
1978	386,303	145,133	2,662	17,530	8,288	2,115
1979	377,394	141,052	2,676	15,758	8,651	1,822
1980	399,112	144,529	2,761	17,366	9,145	1,899
1981	411,814	145,049	2,839	17,774	9,105	1,952
1982	423,464	141,285	2,997	16,878	8,916	1,893
1983	451,812	144,246	3,132	19,549	9,606	2,035
1984	470,871	145,578	3,234	19,905	9,630	2,067
1985	472,714	144,493	3,272	20,264	9,833	2,061
1986	473,068	144,808	3,267	18,868	9,194	2,052
1987	465,780	141,103	3,301	18,428	9,083	2,029
1988	490,768	146,502	3,350	21,263	9,906	2,146
1989	517,272	148,102	3,493	20,177	9,983	2,021
1990	521,703	147,927	3,527	17,193	8,792	1,956
1991	517,410	147,816	3,500	19,810	9,271	2,137
1992	527,913	148,424	3,557	20,180	9,558	2,111
1993	524,804	145,335	3.611	18,447	8,482	2,175
1994	537,338	145,772	3,686	21,111	8,975	2,352
1995	550,600	149,849	3,674	22,015	9,020	2,441
1996	569,733	150,665	3,771	22,332	9,267	2,410
1997	580,841	152,261	3,782	23,580	9,913	2,379
1998	577,350	151,484	3,815	22,784	10,000	2,278
1999	596,485	155,128	3,811	23,272	10,000	2,327

Sources: www.fao.or.com

Table A.2: Rice Harvested Area, Production and Yield of the Major Rice-Exporting Countries, 1961-1999

Year	United States		Vietnam		Myanmar	
	Production (Mt)	Yield (Hg/Ha)	Production (Mt)	Yield (Hg/Ha)	Production (Mt)	Yield (Hg/Ha)
1961	2,458,000	38,227	8,997,400	18,966	6,834,100	16,066
1962	2,996,000	41,785	9,747,040	19,937	7,664,700	16,469
1963	3,187,000	44,449	9,622,670	21,400	7,782,900	15,957
1964	3,319,000	45,906	9,697,030	19,441	8,507,700	17,097
1965	3,460,000	47,693	9,369,700	19,414	8,055,100	16,614
1966	3,856,422	48,442	8,463,500	18,079	6,636,400	14,694
1967	4,054,142	50,851	9,188,400	19,159	7,769,400	16,510
1968	4,723,777	49,600	8,366,150	17,095	8,022,900	16,843
1969	4,168,674	48,399	8,815,000	17,880	7,984,700	17,092
1970	3,801,311	51,763	10,173,300	21,534	8,161,900	16,973
1971	3,890,351	52,882	10,447,000	22,265	8,175,000	17,161
1972	3,875,428	52,679	10,748,200	21,935	7,356,800	16,247
1973	4,207,728	47,911	11,125,000	22,117	8,601,900	17,629
1974	5,097,717	49,770	11,023,290	21,564	8,583,400	17,574
1975	5,825,774	51,086	10,293,600	21,198	9,207,700	18,307
1976	5,245,678	52,268	11,827,200	22,327	9,319,300	18,974
1977	4,500,680	49,450	10,597,100	19,378	9,462,000	19,453
1978	6,040,490	50,257	9,789,900	17,922	10,528,300	21,012
1979	5,985,020	51,548	11,362,900	20,716	10,447,900	23,521
1980	6,629,250	49,461	11,647,400	20,798	13,317,400	27,739
1981	8,289,040	54,015	12,415,200	21,966	14,146,600	29,419
1982	6,968,900	52,791	14,390,200	25,194	14,373,400	31,505
1983	4,523,200	51,532	14,743,300	26,272	14,288,100	30,666
1984	6,296,300	55,523	15,505,600	27,323	14,255,500	30,981
1985	6,122,000	60,704	15,874,800	27,831	14,317,048	30,718
1986	6,049,000	63,340	16,002,900	28,132	14,127,100	30,279
1987	5,879,000	62,271	15,102,600	27,024	13,638,400	30,424
1988	7,253,000	61,801	17,000,000	29,687	13,167,100	29,084
1989	7,007,400	64,465	18,996,304	32,220	13,806,500	29,174
1990	7,080,000	61,975	19,225,104	31,895	13,971,800	29,353
1991	7,230,000	64,244	19,621,904	31,133	13,204,200	28,862
1992	8,149,000	64,292	21,590,304	33,342	14,840,400	29,351
1993	7,081,000	61,762	22,836,600	34,815	16,763,200	30,552
1994	8,971,100	66,851	23,528,300	35,657	18,198,900	31,690
1995	7,887,000	63,010	24,963,700	36,898	17,956,900	29,766
1996	7,771,000	68,485	26,396,700	37,689	17,679,800	30,649
1997	8,300,000	66,099	27,523,900	38,768	16,651,400	30,789
1998	8,366,000	63,475	29,145,500	39,585	17,076,728	31,285
1999	9,345,000	65,750	31,393,800	41,048	20,124,708	32,403

Sources: www.fao.or.com

Table A.2: Rice Harvested Area, Production and Yield of the Major Rice-Exporting Countries, 1961-1999 (Continue)

Year	Pakistan		China		India	
	Production (Mt)	Yield (Hg/Ha)	Production (Mt)	Yield (Hg/Ha)	Production (Mt)	Yield (Hg/Ha)
1961	1,690,000	13,915	56,217,596	20,787	53,494,496	15,419
1962	1,643,000	13,856	65,675,296	23,700	49,825,552	13,959
1963	1,788,000	13,902	76,439,287	26,833	55,497,008	15,498
1964	2,025,000	14,937	85,853,775	28,289	58,962,000	16,171
1965	1,975,000	14,174	90,705,628	29,667	45,883,504	12,936
1966	2,047,000	14,523	98,403,988	31,445	45,657,008	12,952
1967	2,248,000	15,835	96,734,821	31,006	56,418,304	15,484
1968	3,048,000	19,604	97,716,770	31,868	59,641,808	16,134
1969	3,601,000	22,201	97,998,501	31,415	60,644,544	16,094
1970	3,298,400	21,939	113,101,872	34,162	63,337,808	16,849
1971	3,392,600	23,293	118,129,217	33,145	64,602,000	17,110
1972	3,495,212	23,624	116,428,568	32,475	58,867,952	16,046
1973	3,681,984	24,353	124,584,102	34,818	66,077,008	17,259
1974	3,470,148	21,632	127,010,746	35,033	59,650,000	15,744
1975	3,926,184	22,964	128,726,268	35,283	73,352,000	18,582
1976	4,106,178	23,472	129,231,908	34,957	63,051,904	16,372
1977	4,424,406	23,297	131,917,523	36,373	79,005,600	19,613
1978	4,908,000	24,230	140,023,847	39,809	80,608,496	19,912
1979	4,823,700	23,710	146,846,141	42,491	63,475,696	16,105
1980	4,684,800	24,235	142,876,522	41,435	80,312,000	20,002
1981	5,144,550	26,035	146,959,846	43,315	79,883,008	19,623
1982	5,167,050	26,121	164,741,383	48,888	70,771,696	18,497
1983	5,009,250	25,065	172,008,870	50,918	90,048,000	21,833
1984	4,972,800	24,883	181,095,752	53,634	87,552,800	21,272
1985	4,378,400	23,499	171,318,871	52,498	95,817,696	23,292
1986	5,230,000	25,320	174,720,521	53,272	90,779,408	22,052
1987	4,861,400	24,765	176,662,482	54,035	85,338,704	21,991
1988	4,800,300	23,511	171,441,919	52,819	106,368,800	25,486
1989	4,830,150	22,925	182,485,246	55,005	110,310,608	26,160
1990	4,891,200	23,151	191,614,680	57,166	111,517,408	26,125
1991	4,864,650	23,199	185,692,630	56,238	112,042,000	26,271
1992	4,674,150	23,686	188,291,880	57,959	109,001,200	26,092
1993	5,992,050	27,397	179,746,933	58,462	120,400,000	28,303
1994	5,169,750	24,333	177,994,395	58,288	122,640,000	28,645
1995	5,949,750	27,522	187,297,968	60,210	115,440,000	26,972
1996	6,457,200	28,685	197,032,897	62,050	122,500,000	28,226
1997	6,499,500	28,048	202,771,843	63,111	125,534,704	28,879
1998	7,010,700	28,927	200,571,557	63,529	128,928,000	28,909
1999	7,733,400	30,744	200,403,308	63,344	132,300,000	29,659

Sources: www.fao.or.com

Table A.3: Rice Export of the Major Rice-Exporting Countries, 1961-1999 (Mt)

Year	United States	Vietnam	Myanmar	Pakistan
1961	835,078	182,251	1,591,300	174,186
1962	1,050,301	89,763	1,717,563	126,161
1963	1,197,234	229,318	1,712,039	365,025
1964	1,329,119	59,582	1,413,000	256,078
1965	1,549,392	2,955	1,335,000	197,607
1966	1,352,252	12,525	1,127,570	429,393
1967	1,847,972	3,441	540,021	360,172
1968	1,897,922	2,362	351,722	253,800
1969	1,919,812	20,076	549,408	312,700
1970	1,740,526	18,479	640,964	230,000
1971	1,478,521	6,000	810,514	182,193
1972	2,036,679	3,000	524,286	197,980
1973	1,630,044	2,000	145,806	788,876
1974	1,725,581	2,000	214,298	597,240
1975	2,138,747	22,000	291,606	477,650
1976	2,106,804	5,600	623,033	794,548
1977	2,287,544	5,000	661,380	960,164
1978	2,278,778	1,400	348,253	776,600
1979	2,300,623	140,000	590,200	1,015,012
1980	3,054,237	33,300	653,100	1,086,641
1981	3,132,535	0	673,900	1,243,665
1982	2,540,345	8,000	701,300	951,028
1983	2,384,789	46,000	858,400	904,801
1984	2,141,324	83,000	621,800	1,265,000
1985	1,939,975	59,400	581,500	718,686
1986	2,392,033	132,000	597,200	1,316,017
1987	2,471,513	120,400	303,000	1,270,398
1988	2,259,753	91,200	47,800	1,210,199
1989	3,061,098	1,420,000	168,200	854,320
1990	2,473,948	1,624,000	213,600	743,889
1991	2,242,948	1,033,000	183,115	1,204,575
1992	2,164,457	1,945,800	198,800	1,511,844
1993	2,679,731	1,722,000	262,500	1,032,132
1994	2,821,727	1,983,000	933,813	984,325
1995	3,083,609	1,988,000	353,800	1,852,267
1996	2,640,356	3,500,000	92,200	1,600,524
1997	2,296,002	3,574,804	28,300	1,767,206
1998	3,112,693	3,700,000	86,966	1,971,601
1999	2,668,066	4,600,000	36,000	1,791,193

Sources: www.fao.or.com

Table A.3: Rice Export of the Major Rice-Exporting Countries, 1961-1999 (Mt) (Continue)

Year	China	India	Thailand
1961	65,000	34	1,573,696
1962	780,087	155	1,271,263
1963	1,199,441	2,853	1,417,673
1964	1,317,547	2,876	1,896,288
1965	1,192,301	2,654	1,895,223
1966	1,666,724	2,342	1,507,550
1967	1,825,864	4,419	1,482,272
1968	1,587,750	2,610	1,068,185
1969	1,544,453	15,466	1,023,064
1970	1,694,892	27,187	1,063,616
1971	1,508,290	15,854	1,591,384
1972	1,526,182	14,991	2,112,813
1973	2,638,786	17,784	848,717
1974	2,530,101	41,426	1,046,019
1975	1,973,610	18,293	951,260
1976	1,441,434	37,899	1,963,546
1977	1,182,565	18,817	2,931,518
1978	1,672,915	143,537	1,606,745
1979	1,462,404	332,786	2,796,868
1980	1,376,616	483,162	2,796,964
1981	684,721	963,838	3,027,342
1982	775,935	537,261	3,782,775
1983	1,112,620	230,209	3,476,230
1984	1,369,754	198,356	4,615,730
1985	1,045,848	315,070	4,061,715
1986	1,122,615	252,859	4,523,597
1987	1,261,766	388,796	4,443,054
1988	802,245	349,561	5,267,008
1989	383,498	421,750	6,311,409
1990	405,381	505,027	4,017,079
1991	817,605	678,241	4,333,072
1992	1,034,244	580,402	5,151,371
1993	1,506,992	767,681	4,989,219
1994	1,630,314	890,592	4,858,631
1995	235,934	4,913,156	6,197,990
1996	356,854	2,511,974	5,454,350
1997	1,009,916	2,388,788	5,567,519
1998	3,791,615	4,962,941	6,537,492
1999	2,819,010	2,571,000	6,838,900

Sources: www.fao.or.com

Table A.4: The Value of Crop and Rice, and AGDP at Current Price in Thailand, 1961-1998

Year	Crop Area (Rai)	Rice Area (Rai)	Rice Value (Million Baht)	Crop Value (Million Baht)	AGDP (Million Baht)
1961	46958	35349	8038	16574	22369
1962	51349	38696	8820	17071	22929
1963	54180	39715	8170	17377	23776
1964	53210	37316	7348	17252	24205
1965	55140	37247	10019	20860	28440
1966	64612	43772	14863	27806	35819
1967	56523	36295	12100	24440	34015
1968	60828	39602	11373	24626	35955
1969	70558	45231	12344	27995	40016
1970	67760	42433	9473	26776	38493
1971	72189	44319	10967	28084	40786
1972	69856	42375	15409	35960	49919
1973	79268	47995	27453	56443	73233
1974	79699	46949	27909	62229	84735
1975	85484	52229	28312	69666	94063
1976	86418	51045	25650	77509	104657
1977	93095	54684	30166	79069	110929
1978	98711	55844	37428	96180	129094
1979	96183	54086	39813	107980	147076
1980	100541	55628	45331	130372	173806
1981	105534	56554	49292	138886	187886
1982	107751	57504	40682	139852	188742
1983	108923	60038	49697	149973	204443
1984	109954	60186	43344	139547	191278
1985	113737	61457	40257	127051	178533
1986	109141	57463	37158	106997	178140
1987	106336	57169	46231	122809	205592
1988	114806	61912	63825	160179	250384
1989	115230	61744	70629	167521	279947
1990	112550	54949	50704	164641	272935
1991	108910	56581	59468	191392	317084
1992	109134	57248	64560	202393	351889
1993	106517	53015	48589	173200	336429
1994	109035	56095	61337	207000	389559
1995	109638	56870	71348	252500	461734
1996	108587	57920	88999	292279	509585
1997	107238	63728	123317	313448	541865
1998	105419	64189	164164	353256	620183

Sources: AEO and NESDB, Thailand

Table A.5: **World Rice Prices and Export Price (US$/ton)**

Year	5% fob, BKK	Export Price
1961	137	111.37
1962	153	123.53
1963	143	125.16
1964	138	128.28
1965	136	128.69
1966	163	139.05
1967	206	160.96
1968	202	174.54
1969	187	170.41
1970	144	142.00
1971	129	126.51
1972	147	141.67
1973	350	227.57
1974	542	394.43
1975	363	374.57
1976	255	280.74
1977	272	268.95
1978	368	352.68
1979	334	329.56
1980	434	387.28
1981	483	445.34
1982	293	348.91
1983	277	315.07
1984	252	304.77
1985	216	286.13
1986	211	247.5
1987	230	263.65
1988	302	331.72
1989	320	326.22
1990	287	332.38
1991	314	340.69
1992	287	332.06
1993	268	304.52
1994	250	344.28
1995	269	325.9
1996	283	376
1997	280	371.05
1998	292	332.28
1999	240	304.13

Table A.6: Rice Production, Cultivated Area, Harvested Area, and Production of Thailand, 1950-1998

Year	Cultivated Area (1000 rai)	Harvested Area (rai)	Production (metric ton)
1950	34625	33091	6782
1951	37245	35851	7325
1952	33551	32064	6602
1953	38574	37068	8239
1954	34732	28274	5709
1955	36060	33598	7334
1956	37648	36013	8297
1957	31726	26794	5570
1958	35887	32306	7053
1959	37909	32893	6770
1960	37008	35270	7835
1961	38619	35349	8177
1962	41168	38696	9279
1963	41229	39715	10168
1964	40872	37316	9640
1965	40961	37247	9509
1966	46454	43772	11947
1967	41612	36295	9625
1968	45173	39602	10348
1969	47400	45231	13410
1970	46840	42433	13570
1971	47042	44319	13744
1972	45931	42375	12413
1973	52270	47995	14899
1974	49889	46949	13386
1975	55402	52229	15300
1976	53595	51045	15068
1977	56444	54685	13921
1978	62667	55843	17470
1979	58971	54087	15758
1980	60110	57501	17368
1981	59970	56906	17774
1982	60134	55875	16879
1983	62596	60038	19549
1984	62329	60186	19905
1985	63422	61457	20264
1986	61571	57463	18868
1987	58888	57169	18428
1988	64677	61912	21263
1989	64439	61744	20601
1990	61910	54949	17193
1991	59671	56581	20400
1992	60453	57248	19917
1993	59251	53015	18447
1994	60677	56095	21111
1995	63353	56870	22016
1996	63728	57920	22332
1997	64189	61955	23580
1998	68756	62500	22784

Source: OAE, Thailand, various issues

Table A.7: Rice Yield, Fertiliser, Irrigation and R&D in Thailand, 1950-1998

Year	Rice Yield (Kg/Rai)*	Fertiliser Use in Rice (Mt)*	Irrigated Area (1000 Rai)*	Crop R&D Expenditure (Million Baht)**	Rice R&D Expenditure (Million Baht)***
1950	204.94	-	-	-	2.40
1951	204.32	-	-	-	1.70
1952	205.90	-	-	-	4.30
1953	222.27	-	-	-	4.30
1954	201.92	-	-	-	5.40
1955	218.29	-	-	-	10.10
1956	230.39	-	-	-	7.70
1957	207.88	-	-	-	7.90
1958	218.32	-	-	-	18.00
1959	205.82	-	-	55.72	28.03
1960	222.14	-	-	55.48	27.22
1961	231.32	-	-	47.80	21.60
1962	239.79	-	-	72.45	32.13
1963	256.02	-	-	62.99	29.97
1964	258.33	-	-	93.89	43.97
1965	255.30	-	-	106.56	50.31
1966	272.94	-	10531	160.81	83.63
1967	265.19	181142	10841	181.26	81.34
1968	261.30	210318	11184	211.92	95.84
1969	296.48	212905	12077	144.24	52.18
1970	319.80	183155	12145	156.54	52.28
1971	310.12	180196	12365	158.38	52.37
1972	292.93	253038	12445	155.42	53.35
1973	310.43	232250	12488	173.80	31.75
1974	285.12	192742	13420	157.05	34.61
1975	292.94	242772	13981	271.21	49.55
1976	295.19	323332	14392	318.10	49.75
1977	254.57	370000	15437	342.94	53.64
1978	312.84	420000	16641	352.17	55.08
1979	291.35	478500	17764	378.22	59.15
1980	302.05	420940	18772	432.54	67.65
1981	312.34	486208	19822	515.37	68.60
1982	302.09	543304	20752	583.39	77.65
1983	325.61	668944	21656	718.93	95.42
1984	330.72	647933	22866	769.36	102.40
1985	329.73	610000	23889	797.31	106.12
1986	328.35	660000	24447	840.27	101.50
1987	322.34	640000	24976	860.71	103.97
1988	343.44	852209	25756	961.26	116.12
1989	333.65	1110800	25989	1049.67	126.80
1990	312.89	1000000	26488	1245.24	150.43
1991	360.55	851200	27182	1564.20	188.96
1992	347.91	988000	27704	1766.41	213.38
1993	347.96	1361437	28356	2197.00	265.40
1994	376.34	1395852	28685	2468.68	298.22
1995	387.13	1501896	29013	2518.83	304.27
1996	385.57	1555140	29461	3125.98	377.62
1997	380.64	1688115	29680	3301.55	398.83
1998	364.48	1904007	29886	2954.54	356.91

Source: .* from OAE, ** from the budget of DOA, *** details in Appendix B

Table A.8: R&D Expenditure and R&D Knowledge Stock in Rice (1987 price)

Year	R&D Expenditure (million baht)	Accumulative R&D Expenditure (million baht)	CPI (1987 =100)
1950	16.81	16.81	14.28
1951	10.75	27.55	15.82
1952	24.76	52.31	17.37
1953	22.29	74.60	19.29
1954	28.27	102.87	19.1
1955	49.85	152.72	20.26
1956	35.95	188.67	21.42
1957	34.69	223.37	22.77
1958	74.63	297.99	24.12
1959	122.14	420.13	22.95
1960	114.57	534.70	23.76
1961	84.66	619.36	25.52
1962	121.45	740.81	26.46
1963	113.28	854.08	26.46
1964	167.52	1021.61	26.25
1965	191.38	1212.98	26.29
1966	305.68	1518.66	27.36
1967	285.02	1803.68	28.54
1968	329.92	2133.61	29.05
1969	175.34	2308.94	29.76
1970	175.84	2484.78	29.73
1971	175.27	2660.05	29.88
1972	170.33	2830.38	31.32
1973	87.76	2918.14	36.18
1974	76.95	2995.09	44.98
1975	104.59	3099.67	47.38
1976	100.83	3200.50	49.34
1977	101.02	3301.53	53.09
1978	96.13	3397.65	57.30
1979	93.94	3491.59	62.97
1980	89.75	3581.34	75.37
1981	80.77	3662.11	84.92
1982	86.87	3748.98	89.39
1983	102.92	3851.89	92.72
1984	109.49	3961.39	93.52
1985	110.78	4072.17	95.80
1986	104.04	4176.21	97.56
1987	103.97	4280.18	100.00
1988	111.86	4392.05	103.80
1989	115.94	4507.99	109.37
1990	129.79	4637.77	115.90
1991	154.19	4791.96	122.51
1992	167.31	4959.27	127.49
1993	201.32	5160.60	131.80
1994	215.36	5375.96	138.60
1995	207.69	5583.65	146.52
1996	243.59	5827.24	155.04
1997	243.60	6070.84	163.72
1998	201.72	6272.56	176.93

Table A.9: Fertiliser, Irrigation, R&D per Unit of Rai, and Farm Price of Paddy (1987 price)

Year	Fertiliser Use in Rice (Kg/Rai)	The Ratio of Irrigated Area /Rice Area	R&D Expenditure (Baht/Rai)	R&D Knowledge Stock (Baht/ Rai)	Price of Paddy (Baht/Kg)
1967	4.990825	0.298691	6.84955	43.34528	3.99
1968	5.310792	0.28241	7.303534	47.2319	3.34
1969	4.707059	0.267007	3.699086	48.71188	2.89
1970	4.316334	0.286216	3.753958	53.04822	2.12
1971	4.065886	0.279	3.725924	56.54635	2.68
1972	5.971398	0.293687	3.708284	61.6224	2.23
1973	4.839046	0.260194	1.678953	55.82815	3.40
1974	4.105348	0.285842	1.54243	60.03503	4.29
1975	4.648222	0.267687	1.887784	55.94879	4.43
1976	6.334254	0.281947	1.881311	59.71646	3.91
1977	6.766024	0.282282	1.789803	58.49209	4.52
1978	7.521086	0.297999	1.533903	54.21757	3.96
1979	8.846858	0.328437	1.592978	59.20863	4.30
1980	7.320568	0.326464	1.493033	59.57974	4.21
1981	8.544055	0.348321	1.346915	61.06574	3.39
1982	9.723562	0.371406	1.444543	62.34374	3.29
1983	11.14201	0.360707	1.644119	61.53579	3.01
1984	10.76551	0.379924	1.756719	63.55611	2.49
1985	9.925639	0.388713	1.746674	64.20747	2.40
1986	11.48565	0.42544	1.689791	67.82752	2.64
1987	11.19488	0.436875	1.765619	72.68343	3.85
1988	13.76484	0.416002	1.729582	67.90739	3.83
1989	17.99041	0.420916	1.799245	69.95744	3.32
1990	18.19869	0.482046	2.096366	74.91154	3.11
1991	15.04392	0.480417	2.583956	80.30636	3.11
1992	17.25824	0.483927	2.76767	82.03521	2.58
1993	25.68022	0.53487	3.3978	87.09723	2.83
1994	24.88372	0.511373	3.549282	88.5996	2.78
1995	26.40928	0.510164	3.278274	88.13547	3.25
1996	26.84979	0.508647	3.82236	91.4392	3.56
1997	27.24744	0.479055	3.795051	94.57755	4.25
1998	30.46411	0.47817	2.93382	91.22921	3.93

Source: Table A.7 divided by cultivate area of rice

<u>Table A.10</u> : Index of Major and Second Rice Yield and CV during 1974-1998, 1974 and 1980 = 100

Year	Major Yield Index	Major CV Index	Second Yield Index	Second CV Index	Total Yield Index	Total CV Index
1974	100	100	-	-	100	100
1975	97	100	-	-	97	100
1976	101	91	-	-	101	91
1977	101	88	-	-	101	88
1978	95	115	-	-	95	115
1979	101	97	-	-	101	97
1980	100	103	100	100	104	103
1981	108	113	108	104	116	119
1982	116	88	113	84	120	93
1983	109	83	103	80	113	87
1984	113	79	113	78	120	86
1985	116	81	109	75	121	85
1986	116	76	108	71	120	80
1987	115	89	102	74	118	92
1988	116	101	117	70	120	101
1989	119	88	119	74	125	93
1990	121	90	100	105	121	81
1991	110	81	119	94	119	86
1992	126	84	120	88	132	89
1993	124	82	120	95	131	114
1994	130	85	115	93	132	94
1995	133	89	117	107	137	94
1996	134	95	127	105	143	106
1997	132	88	129	92	141	98
1998	133	91	121	104	139	96

Source: Calculate from the provincial data in various issues of Agricultural Statistics of Thailand, OAE.

Table A.11: Rice Yield, and Average Monthly Income per Household and per Capita, 1996

Province	RiceYield* (kg/rai)	Per Household Income** (Baht)	Per Capita Income** (Baht)
Nakhon Phanom	297.35	6196	1556
Sakon Nakon	255.11	7746	1929
Nong Khai	301.41	8733	2061
Udon Thani	257.61	7766	1937
Nong Bua Lam Phu	266.64	7147	1699
Loei	402.95	6875	1727
Mukdahan	292.91	7455	1701
Yasopthon	248.45	6581	1725
Ubon Ratchathani	275.13	6950	1640
Amnat Charoen	295.69	7027	1732
Kalasin	351.53	6079	1501
Khon Kaen	265.72	9438	2489
Maha Sarakham	281.81	5171	1355
Roi Et	280.61	6746	1823
Buri Rum	285.33	6446	1568
Si Sa Ket	290.27	7149	1760
Surin	276.37	6517	1595
Chaiyaphum	266.89	7166	1860
Nakorn Ratchasima	299.80	8803	2236
Nakorn Sawan	459.54	8551	2587
Phetchabun	585.80	8204	2211
Uthai Thani	334.93	8203	2338
Kamphaeng Phet	533.99	8142	2289
Tak	402.38	7604	2202
Phichit	560.68	10324	2992

Note: * data from AEO
** data from NSO (1996)

Table A.11: Rice Yield, and Average Monthly Income per Household and per Capita (Continue), 1996

Province	RiceYield* (kg/rai)	Per Household Income**(Baht)	Per Capita Income** (Baht)
Phitsanulok	526.81	7587	2275
Nan	568.56	6913	1785
Phrae	624.12	8261	2400
Lampang	481.74	8208	2352
Sukothai	364.70	8320	2454
Uttaradit	598.84	8181	2364
Chiang Mai	477.54	9806	3080
Chiang Rai	510.63	7955	2286
Mae Hong Son	429.33	6187	1452
Lamphun	501.52	8735	2612
Phayao	525.70	6129	1844
Lop Buri	424.23	6331	2518
Saraburi	459.35	10582	2958
Chai Nat	688.71	9574	2798
Nakhon Nayok	524.79	9526	2627
Nakhon Pathom	719.80	14737	3836
Nonthaburi	818.70	36888	10581
Pathum Thani	662.70	15539	3842
Ayutthaya	404.39	11376	3080
Sing Buri	889.80	9525	2779
Suphan Buri	719.13	7428	2007
Ang Thong	592.84	11414	3509
BKK	621.61	21550	7009
Kanchanaburi	393.39	10230	2616
Prachuap Khiri Khan	288.84	7923	2197

Note: * data from AEO
** data from NSO (1996)

Table A.11: Rice Yield, and Average Monthly Income per Household and per Capita, 1996 (Continue)

Province	RiceYield* (kg/rai)	Per Household Income** (Baht)	Per Capita Income** (Baht)
Phetchaburi	548.64	8117	2148
Ratchaburi	505.35	12621	3379
Chachoengsao	587.48	11820	3046
Prachin Buri	293.24	8117	2148
Sa Kaeo	292.03	7189	2114
Samut Prakan	616.45	17145	5207
Samut Sakhon	570.41	15997	4845
Samut Songkhram	566.33	10925	3123
Chon Buri	304.99	12223	3524
Rayong	331.97	13254	3868
Chanthaburi	314.99	12410	3231
Trat	275.05	11696	3353
Chumphon	265.74	9874	2922
Nakhon Si Thammarat	320.42	9681	2385
Phathalung	394.65	8474	2232
Songkhla	397.39	11089	3205
Surat Thani	322.61	12771	3305
Krabi	295.76	8758	2226
Trang	367.40	11733	2836
Phangnga	244.78	8696	2585
Phuket	323.81	15437	4683
Ranong	269.23	9359	2562
Satun	359.07	8977	1972
Narathiwat	332.65	6715	1612
Pattani	325.74	6876	1493
Yala	285.59	7114	1852

Note: * data from AEO
** data from NSO (1996)

Table A.12: Rice Yield, Household and per Capita Income of Farmers, 1998/99

Province	RiceYield* (kg/rai)	Per Household Income** (Baht)	Per Capita Income** (Baht)
Nakhon Phanom	292.93	45627.79	8691.01
Sakon Nakon	295.76	50865.58	7266.51
Nong Khai	351.95	78970.25	13347.08
Udon Thani	294.54	54985.35	10473.4
Nong Bua Lam Phu	283.86	128261.76	26087.14
Loei	394.7	110560.8	22486.94
Mukdahan	248.06	55577	9135.95
Yasopthon	272.4	65781.74	11276.87
Ubon Ratchathani	248.79	37533.72	5426.56
Amnat Charoen	259.55	102398.47	14985.14
Kalasin	496.62	76877.58	14879.53
Khon Kaen	289.41	82545.17	18343.37
Maha Sarakham	294.73	69861.45	13099.02
Roi Et	255.33	7784.08	1796.33
Buri Rum	280.95	51606.31	9382.97
Si Sa Ket	278.39	87315.98	14757.63
Surin	281.86	116170.52	22484.62
Chaiyaphum	287.88	100459.94	14017.67
Nakorn Ratchasima	273.16	81677.83	16612.44
Nakorn Sawan	354.18	68298.59	13659.72
Phetchabun	461.63	39977.7	10903.01
Uthai Thani	405.72	158579.36	27984.59
Kamphaeng Phet	507.92	28028.13	8461.32
Tak	393.63	36159.25	14463.7
Phichit	552.38	57027.5	12005.79

Note: * data from Agricultural Statistics of Thailand Crop Year 1998/99, OAE
** data from A Socio-economic Survey of Agricultural Household and Labor, 1998/1999 by OAE

Table A.12: Rice Yield, Household and per Capita Income of Farmers, 1998/99 (continue)

Province	RiceYield* (kg/rai)	Per Household Income**(Baht)	Per Capita Income** (Baht)
Phitsanulok	495.92	86779.14	23141.1
Nan	462.55	100598.71	21948.81
Phrae	517.21	89465.17	22366.29
Lampang	443.92	42750.82	11659.31
Sukothai	504.47	60596.81	11728.41
Uttaradit	431.14	80497.15	20124.29
Chiang Mai	477.26	138940.27	32691.83
Chiang Rai	459.07	63557.17	17736.88
Mae Hong Son	432.61	85423.58	22479.89
Lamphun	468.27	55735.8	23063.09
Phayao	446.75	68371.31	13450.09
Lop Buri	420.35	57180.22	12946.46
Saraburi	428.21	99933.3	23061.53
Chai Nat	593.65	165813.36	32092.91
Nakhon Nayok	423.15	141771.46	25391.9
Nakhon Pathom	737.05	153903.98	31302.51
Nonthaburi	786.25	716700.61	145769.62
Pathum Thani	715.08	487256.67	56221.92
Ayutthaya	540.03	362214.07	61508.05
Sing Buri	647.4	403464.89	83475.49
Suphan Buri	735.13	69414.42	17722.83
Ang Thong	540.14	81376.83	17437.89
BKK	629.93	140819.77	23969.32
Kanchanaburi	437.02	172802.39	240420.72
Prachuap Khiri Khan	330.43	180445.51	42963.22

Note: * data from Agricultural Statistics of Thailand Crop Year 1998/99, AEO
** data from A Socio-economic Survey of Agricultural Household and Labor, 1998/1999 by OAE

Table A.12: Rice Yield, Household and per Capita Income of Farmers, 1998/99 (continue)

Province	RiceYield* (kg/rai)	Per Household Income** (Baht)	Per Capita Income** (Baht)
Phetchaburi	505.55	150070.44	25435.67
Ratchaburi	581.68	16276.56	4413.98
Chachoengsao	544.21	764952.04	143428.51
Prachin Buri	310.81	162450.03	29536.37
Sa Kaeo	363.29	63083.75	14843.24
Samut Prakan	615.89	26190	4690.75
Samut Sakhon	613.12	226891.51	39459.39
Samut Songkhram	601.59	309074.53	60801.55
Chon Buri	300.74	93111.31	14143.49
Rayong	364.15	87559.08	16164.75
Chanthaburi	335.48	83449.41	14726.37
Trat	338.01	131472.93	26294.59
Chumphon	228.7	114308.81	20473.22
Nakhon Si Thammarat	344.24	130730.08	19367.42
Phathalung	406.17	68877.9	13775.58
Songkhla	390.93	118365.83	26303.52
Surat Thani	316.88	41254.29	9520.22
Krabi	288.29	58167.63	8409.78
Trang	317.25	52056.02	10770.21
Phangnga	297.46	161748.48	28130.17
Phuket	307.62	95778.45	14366.77
Ranong	273	107341.94	22598.3
Satun	349.3	57366.26	9976.74
Narathiwat	320.18	126696.83	19491.82
Pattani	343.27	52991.44	11998.06
Yala	331.71	57098.25	9516.38

Note: * data from Agricultural Statistics of Thailand Crop Year 1998/99, AEO
** data from A Socio-economic Survey of Agricultural Household and Labor, 1998/1999 by OAE

Table A.13: Rice Yield and Poverty in Thailand, 1996 and 1998

Province	1996		1998	
	RiceYield* (Kg/Rai)	% of Poor**	RiceYield* (Kg/Rai)	% of Poor**
Nakhon Phanom	297.35	28.23	260.70	26.6
Sakon Nakon	255.11	36.19	301.59	33.6
Nong Khai	301.41	21.21	292.01	28.8
Udon Thani	257.61	11.81	259.90	24.4
Nong Bua Lam Phu	266.64	20.88	297.03	28.7
Loei	402.95	25.65	338.36	23.7
Mukdahan	292.91	22.61	255.83	18.8
Yasopthon	248.45	32.15	263.47	31.3
Ubon Ratchathani	275.13	23.83	259.66	6.3
Amnat Charoen	295.69	30.95	246.20	18.8
Kalasin	351.53	36.89	343.75	34.5
Khon Kaen	265.72	4.56	282.76	11.4
Maha Sarakham	281.81	25.62	290.96	4.8
Roi Et	280.61	12.74	288.40	32.7
Buri Rum	285.33	18.93	260.24	25.1
Si Sa Ket	290.27	27.36	301.75	30.4
Surin	276.37	22.06	311.79	37.8
Chaiyaphum	266.89	7.81	254.07	29.8
Nakorn Ratchasima	299.80	9.49	273.96	22.3
Nakorn Sawan	459.54	6.43	366.51	4.2
Phetchabun	585.80	9.34	450.27	15.9
Uthai Thani	334.93	10.3	344.12	24.6
Kamphaeng Phet	533.99	8.36	456.54	7.8
Tak	402.38	16.31	381.18	18.1
Phichit	560.68	5.58	533.67	4.6

Note: * data from OAE, ** data from NESB

Appendix A.13: Rice Yield and Poverty in Thailand, 1996 and 1998 (continue)

Province	1996		1998	
	RiceYield* (Kg/Rai)	% of Poor**	RiceYield* (Kg/Rai)	% of Poor**
Phitsanulok	526.81	15.37	498.11	4.5
Nan	568.56	24.31	464.44	4.6
Phrae	624.12	8.59	519.48	2.1
Lampang	481.74	7.3	440.36	9.4
Sukothai	364.70	10.94	414.22	16.3
Uttaradit	598.84	9.29	518.34	8.8
Chiang Mai	477.54	10.23	533.13	6.0
Chiang Rai	510.63	13.76	454.30	5.0
Mae Hong Son	429.33	43.06	374.32	44.5
Lamphun	501.52	5.3	465.48	10.0
Phayao	525.70	16.67	450.35	6.5
Lop Buri	424.23	12.9	441.96	14.6
Saraburi	459.35	3.88	423.00	3.2
Chai Nat	688.71	6.99	652.11	12.2
Nakhon Nayok	524.79	0.78	358.20	2.3
Nakhon Pathom	719.80	2.4	742.89	0.9
Nonthaburi	818.70	1.48	779.38	0
Pathum Thani	662.70	0.29	702.65	2.1
Ayutthaya	404.39	2.46	512.03	4.1
Sing Buri	889.80	7.17	664.43	15.7
Suphan Buri	719.13	19.88	682.23	10.3
Ang Thong	592.84	0	584.40	7.6
BKK	621.61	0.32	675.29	0.5
Kanchanaburi	393.39	8.59	455.12	9.0
Prachuap Khiri Khan	288.84	11.9	374.09	13.1

Note: * data from AEO
** data from NESDB

Appendix A.13: Rice Yield and Poverty in Thailand, 1996 and 1998 (continue)

Province	1996		1998	
	RiceYield* (Kg/Rai)	% of Poor**	RiceYield* (Kg/Rai)	% of Poor**
Phetchaburi	548.64	1.04	496.50	2.3
Ratchaburi	505.35	3.69	506.68	1.9
Chachoengsao	587.48	8.2	545.51	4.5
Prachin Buri	293.24	6.92	307.90	8.5
Sa Kaeo	292.03	0.09	285.09	22.8
Samut Prakan	616.45	0.94	592.73	0
Samut Sakhon	570.41	1.11	593.67	3.0
Samut Songkhram	566.33	1.37	530.66	1.2
Chon Buri	304.99	0.65	270.44	2.0
Rayong	331.97	3.11	322.61	0.8
Chanthaburi	314.99	4.63	315.28	13.5
Trat	275.05	8.79	313.32	12.1
Chumphon	265.74	12.42	295.51	6.2
Nakhon Si Thammarat	320.42	10.81	340.99	17.3
Phathalung	394.65	7.38	408.41	7.2
Songkhla	397.39	2.82	393.95	1.6
Surat Thani	322.61	1.57	440.35	1.2
Krabi	295.76	6.58	278.84	10.5
Trang	367.40	4.94	353.20	8.1
Phangnga	244.78	13.56	373.06	25.0
Phuket	323.81	1.64	478.79	1.2
Ranong	269.23	16.6	268.05	14.5
Satun	359.07	3.58	371.83	16.3
Narathiwat	332.65	32.27	333.60	45.6
Pattani	325.74	30.85	340.16	20.7
Yala	285.59	26.13	260.90	37.9

Note: * data from AEO
** data from NESDB

Appendix B: Note on Data

The sources and description of some data in Appendix A can be summarized as follows:

Rice Production and Productivity

Rice productions were collected from the major rice growing areas and second rice cultivation areas of the whole country in both non-irrigated (rain fed) and irrigated area during 1950 to 1998. The rice productivity (rice yield) using as a dependent variable in this study is derived from the ratio of total rice production of paddy and total harvested area. The time series data and cross-provincial data of total production, harvested area, and yield of paddy between 1950 and 1998 were taken from various issues of the Agricultural Statistics of Thailand reported by the Office of Agricultural Economics (OAE). The rice productivity are presented in kilograms per rai (1 rai = 0.16 ha). The time series data of production, area and productivity of rice in Thailand from the year 1967 to 1998 is presented in Table A.6 and A.7 (Appendix A), and the cross-provincial data is represented in Table A.11-A.12 (Appendix A).

Cultivated and Harvested Area

The time-series data on cultivated area and harvested area of rice in major rain fed and second rice cultivation between 1967 and 1998 were also taken from various issues of the Agricultural Statistics of Thailand. The time series data for national level is presented in Table A.6 (Appendix A). Rice productivity is calculated by the ratio of rice production and harvested area.

Chemical Fertilizer

Chemical fertilizer refers to the gross weight of fertiliser consumed in rice field both major rain fed and second rice cultivation areas which were averaged from data of every province throughout the country. Data between 1967 and 1998 were also collected from many issues of Agricultural Statistics of Thailand. The rate of chemical fertilizer use in this study was calculated in kilograms per unit of cultivated area of rice. The time series data of total fertilizer used in rice field and fertilizer used per unit of cultivated area were available only in the year 1967 to 1997, reported in Table A.7 and A.9 (Appendix A).

Irrigation

Irrigated area is used as a proxy of irrigation expansion. The data of irrigated area was collected between 1967 and 1998 from many various issues of Agricultural Statistics of Thailand. The ratio of irrigated area per cultivated area of rice in each year is used as a variable to explain the rice yield. The time series data of total irrigated area and irrigated area per unit of cultivated area were available only between 1967 and 1968, reported in Table A.7 and A.9 (Appendix A).

R&D expenditure and R&D Knowledge Stock

Rice research expenditure was complied from many sources. The initial period of R&D investment in rice is dated back to 1950. The R&D expenditure for rice prior to 1950 were not available. The data between 1950 and 1958 was taken from ESCAP (1977). The R&D expenditure for rice between 1959 and 1998 was based on the government's budget reported in the Royal Thai Government Gazette. The data between 1959 and 1972 was collected from the budget of the Department of Rice at that time. Since 1972, the Department of Rice was dissolved and its tasks was concluded into Rice Research Institute under the Department of Agriculture, thus the data between 1973 and 1998 was estimated from the average ratio of average rice research budget to average budget of DOA shown in Table 2.6 in the report of Somporn and Poapongsakorn (1995). This R&D expenditure includes personnel cost, material cost, managerial or administrative cost, and other infrastructure used for research and extension purposes both at the central office in Bangkok and experimental stations in countryside. The R&D expenditure was deflated by consumer price index (CPI) at 1987 price in order to transform the data into the real term.

The proxy of capital stock of knowledge is the sum of the R&D expenditure dated back to 1950. This dated-back period should be suitable to represent the R&D knowledge stock at the initial R&D investment period. The R&D expenditure between 1950 and 1953 indicated a very little amount of investment in rice R&D, only 2.4 million Baht in 1950, 1.7 million Baht in 1951, and 4.3 million Baht in 1952 and 1953. Therefore, it implies that there was a little R&D expenditure for rice before 1950.* The figures before 1950 was so little so that it could be neglected.

Consumer Price Index (CPI)

Consumer price index was used to deflate the current price of R&D expenditure and farm price of rice into real term. This index is a constant price at 1987. This CPI was derived from Database DX, developed and marketed by ECONDATA P/L in Melbourne, Australia.

Prices of Rice

Rice prices were recorded at the farm gate, measured in Baht per kilogram of paddy. The lists of price of rice was reported in various issues of Agricultural Statistics of Thailand. The nominated price was deflated to the real price with the CPI (1987 price).

Rice Yield Variation

Rice yield variation was measured as the coefficient of variation (CV), defined as the ratio of the standard of deviation and the mean of rice yield. Provincial data between 1974 and 1998 were used. The cross-sectional data during the same period were also collected from the Agricultural Statistics of Thailand reported by the Office of Agricultural Economics (OAE).

Income

Cross-sectional provincial data of total household income and per capita income in Thailand in 1996 were surveyed by NSO from farm and non-farm households in the whole country. The results of survey were reported in "Report of the 1996 Household Socio-economic Survey: Whole Kingdom'. Cross-sectional provincial data of household income and per capita income of farmers in Thailand in crop year 1998/99 were surveyed by OEA between 1st April and 31st March 1999. The results of the survey were reported in "A Socio-economic Survey of Agricultural Household and Labour Crop Year 1998/1999". The household and per capita incomes of farmers comprise both of farm income and off-farm income.

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* See more detail in Welsch and Tongpan 1973.

Percentage of Poverty Level

Time-series data of the percentage of people living in poverty in Thailand was available only 12 years for the whole kingdom and 7 years for regional data. The time series data were collected from many sources. The data in 1962/63 and 1968/69 recorded by Meesuk, data in 1981 and 1986 were collected by TDRI, and the rest was collected in every two-year since 1988 by NESDB. The poverty level was defined as the minimum level of income needed to satisfy basic subsistence requirements, and to count the number of people below that line. Moreover, cross-provincial data of poverty level was available only in 1996 and 1998 surveyed by NESDB.

APPENDIX C: OLS Estimation for Rice Yield and Fertilizer Response Function

Table C.1: Equation (5.4)

Ordinary Least Squares Estimation
****
Dependent variable is LNY

32 observations used for estimation from 1967 to 1998
****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-2.9866	1.9359	-1.5427[.135]
LNF	-.027487	.047776	-.5753[.570]
LNIR	-.042364	.095349	-.4443[.661]
LNRD	.11578	.025803	4.4869[.000]
LNKRD	.27081	.082588	3.2790[.003]
LNH	.39519	.12983	3.0439[.005]

****

R-Squared	0.92278	R-Bar-Squared	.90793
S.E. of Regression	0.033667	F-stat. F(5, 26)	62.1417[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	0.029471	Equation Log-likelihood	66.4355
Akaike Info. Criterion	60.4355	Schwarz Bayesian Criterion	56.0383
DW-statistic	2.2009		

****

Diagnostic Tests
****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .37728[.539]	F(1, 25) = .29827[.590]
B:Functional Form	CHSQ(1) = .53080[.466]	F(1, 25) = .42168[.522]
C:Normality	CHSQ(2) = 2.3910[.303]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .13941[.709]	F(1, 30) = .13127[.720]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.2: Equation (5.5)

Ordinary Least Squares Estimation

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-2.5928	2.2543	-1.1502[.260]
LNF	.055509	.047275	1.1742[.251]
LNIR	.023818	.10872	.21907[.828]
LNRD	.089538	.028620	3.1285[.004]
LNH	.38156	.15139	2.5203[.018]

R-Squared	0.89085	R-Bar-Squared	.87468
S.E. of Regression	0.039280	F-stat. F(4,27)	55.0908[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	0.041658	Equation Log-likelihood	60.8979
Akaike Info. Criterion	55.8979	Schwarz Bayesian Criterion	52.2336
DW-statistic	1.6622		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 0.7493[.387]	F(1, 26) = 0.62345[.437]
B:Functional Form	CHSQ(1) = 4.9635[.026]	F(1, 26) = 4.7732[.038]
C:Normality	CHSQ(2) = 1.1108[.574]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .47742[.490]	F(1, 30) = 0.45436[.505]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.3: Equation (5.6)

Ordinary Least Squares Estimation
****
Dependent variable is LNY
32 observations used for estimation from 1967 to 1998
****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	3.7566	1.5952	2.3550[.026]
LNF	.095270	.051196	1.8609[.074]
LNIR	-.055125	.12458	-.44249[.662]
LNKRD	.15590	.10263	1.5190[.140]
LNH	.022176	.13035	.17012[.866]

****

R-Squared	0.86299	R-Bar-Squared	.84269
S.E. of Regression	.044008	F-stat. F(4, 27)	42.5163[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	0.11096
Residual Sum of Squares	.052291	Equation Log-likelihood	57.2608
Akaike Info. Criterion	52.2608	Schwarz Bayesian Criterion	48.5964
DW-statistic	1.7845		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .37140[.542]	F(1, 26) = 0.3053[.585]
B:Functional Form	CHSQ(1) = 9.8861[.002]	F(1, 26) = 11.6234[.002]
C:Normality	CHSQ(2) = 3.9438[.139]	Not applicable
D:Heteroscedasticity	CHSQ(1) = 0.036524[.848]	F(1, 30) = .034281[.854]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.4: Equation (5.7)

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	3.0341	1.5577	1.9478[.062]
LNF	.13041	.046724	2.7911[.009]
LNIR	-.011131	.12396	-.089791[.929]
LNH	.067333	.12984	.51857[.608]

****

R-Squared	0.85128	R-Bar-Squared	0.83535
S.E. of Regression	0.045023	F-stat. F(3, 28)	53.4249[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	0.11096
Residual Sum of Squares	0.056759	Equation Log-likelihood	55.9488
Akaike Info. Criterion	51.9488	Schwarz Bayesian Criterion	49.0173
DW-statistic	1.6982		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .75968[.383]	F(1, 27)= .65657[.425]
B:Functional Form	CHSQ(1) = 8.8845[.003]	F(1, 27) = 10.3774[.003]
C:Normality	CHSQ(2) = 1.8186[.403]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .060895[.805]	F(1, 30) = .057198[.813]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.5: Equation (5.8)

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-2.5487	2.2068	-1.1549[.258]
LNF	.064167	.025501	2.5163[.018]
LNRD	.088894	.027980	3.1770[.004]
LNH	.39531	.13540	2.9196[.007]

****

R-Squared	.8906	R-Bar-Squared	0.87894
S.E. of Regression	.03860	F-stat. F(3, 28)	76.0232[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	0.11096
Residual Sum of Squares	.0417	Equation Log-likelihood	60.8695
Akaike Info. Criterion	56.8695	Schwarz Bayesian Criterion	53.9380
DW-statistic	1.6778		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .66702[.414]	F(1, 27) = .57478[.455]
B:Functional Form	CHSQ(1) = 4.1616[.041]	F(1, 27) = 4.0363[.055]
C:Normality	CHSQ(2) =1.1448[.564]	Not applicable
D:Heteroscedasticity	CHSQ(1)= .45672[.499]	F(1, 30) = .43437[.515]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.6: Equation (5.9)

Ordinary Least Squares Estimation

****

Dependent variable is LNY

32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	3.6996	1.5670	2.3610[.025]
LNF	.079687	.036621	2.1760[.038]
LNKRD	.14534	.098376	1.4774[.151]
LNH	-.010205	.10631	-.095988[.924]

****

R-Squared	.86200	R-Bar-Squared	.84721
S.E. of Regression	.043371	F-stat. F(3, 28)	58.2975[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.052670	Equation Log-likelihood	57.1451
Akaike Info. Criterion	53.1451	Schwarz Bayesian Criterion	50.2137
DW-statistic	1.7828		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .36331[.547]	F(1, 27) = .31007[.582]
B:Functional Form	CHSQ(1) = 10.7905[.001]	F(1, 27) = 13.7365[.001]
C:Normality	CHSQ(2) = 3.9574[.138]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .006009[.938]	F(1, 30) = .0056346[.941]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.7: Equation (5.10)

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-3.0503	1.9017	-1.6040[.120]
LNF	-.039815	.038310	-1.0393[.308]
LNRD	.11612	.025405	4.5706[.000]
LNKRD	.26304	.079508	3.3084[.003]
LNH	.37143	.11653	3.1874[.004]

****

R-Squared	.92220	R-Bar-Squared	.91067
S.E. of Regression	.033163	F-stat. F(4, 27)	80.0060[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.029694	Equation Log-likelihood	66.3145
Akaike Info. Criterion	61.3145	Schwarz Bayesian Criterion	57.6502
DW-statistic	2.1861		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .31128[.577]	F(1, 26) = .25540[.618]
B:Functional Form	CHSQ(1) = .86478[.352]	F(1, 26) = .72215[.403]
C:Normality	CHSQ(2) = 1.8597[.395]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .20545[.650]	F(1, 30) = .19385[.663]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

<u>Table C.8</u>: Equation (5.11)

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	3.0324	1.5307	1.9810[.057]
LNF	.12658	.018635	6.7925[.000]
LNH	.059768	.097100	.61554[.543]

****

R-Squared	.85124	R-Bar-Squared	.84098
S.E. of Regression	.044247	F-stat. F(2, 29)	82.9713[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.056776	Equation Log-likelihood	55.9441
Akaike Info. Criterion	52.9441	Schwarz Bayesian Criterion	50.7455
DW-statistic	1.6954		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .73350[.392]	F(1, 28) = .65687[.425]
B:Functional Form	CHSQ(1) = 8.6387[.003]	F(1, 28) =10.3540[.003]
C:Normality	CHSQ(2) = 1.8409[.398]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .070449[.791]	F(1, 30) = .066192[.799]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.9: Equation (5.12)

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-2.4107	1.6364	-1.4732[.152]
LNIR	-.074223	.076653	-.96830[.341]
LNRD	.10727	.020889	5.1353[.000]
LNKRD	.24564	.069172	3.5511[.001]
LNH	.38648	.12734	3.0351[.005]

R-Squared	.92180	R-Bar-Squared	.91021
S.E. of Regression	.033248	F-stat. F(4, 27)	79.5658[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.029846	Equation Log-likelihood	66.2331
Akaike Info. Criterion	61.2331	Schwarz Bayesian Criterion	57.5688
DW-statistic	2.1989		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .3608[.548]	F(1, 26) = .29654[.591]
B:Functional Form	CHSQ(1) = .3681[.544]	F(1, 26) = .30261[.587]
C:Normality	CHSQ(2) = 3.0840[.214]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .09111[.763]	F(1, 30) = .085664[.772]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.10: Equation (5.13)

Ordinary Least Squares Estimation

****

Dependent variable is LNY

32 observations used for estimation from 1967 to 1998

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-4.1068	1.8616	-2.2060[.036]
LNIR	.13053	.060073	2.1729[.038]
LNRD	.10656	.024844	4.2890[.000]
LNH	.40244	.15136	2.6589[.013]

R-Squared	.88528	R-Bar-Squared	.87298
S.E. of Regression	.039544	F-stat. F(3, 28)	72.0207[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.043785	Equation Log-likelihood	60.1011
Akaike Info. Criterion	56.1011	Schwarz Bayesian Criterion	53.1696
DW-statistic	1.4837		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 1.7432[.187]	F(1, 27) = 1.5555[.223]
B:Functional Form	CHSQ(1) = 6.2157[.013]	F(1, 27) = 6.5087[.017]
C:Normality	CHSQ(2) = 1.2510[.535]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .51364[.474]	F(1, 30) = .48939[.490]

A:Lagrange multiplier test of residual serial correlation

B:Ramsey's RESET test using the square of the fitted values

C:Based on a test of skewness and kurtosis of residuals

D:Based on the regression of squared residuals on squared fitted values

Table C.11: Equation (5.14)

Ordinary Least Squares Estimation
****
Dependent variable is LNY
32 observations used for estimation from 1967 to 1998
****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	3.3402	1.6474	2.0276[.052]
LNIR	.10435	.094314	1.1064[.278]
LNKRD	.24221	.095496	2.5363[.017]
LNH	-.074178	.12478	-.59449[.557]

****

R-Squared	.84542	R-Bar-Squared	82885
S.E. of Regression	.045903	F-stat. F(3, 28)	51.0442[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.058997	Equation Log-likelihood	55.3300
Akaike Info. Criterion	51.3300	Schwarz Bayesian Criterion	48.3985
DW-statistic	1.5550		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 1.3576[.244]	F(1, 27) = 1.1962[.284]
B:Functional Form	CHSQ(1) =14.7881[.000]	F(1, 27) = 23.1978[.000]
C:Normality	CHSQ(2) = 2.9609[.228]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .10755[.743]	F(1, 30) = .10116[.753]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.12: Equation (5.15)

Ordinary Least Squares Estimation

****

Dependent variable is LNY

32 observations used for estimation from 1967 to 1998

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	1.6298	1.6378	.99514[.328]
LNIR	.30509	.055888	5.4589[.000]
LNH	-.055407	.13572	-.40824[.686]

R-Squared	.80990	R-Bar-Squared	.79679
S.E. of Regression	.050018	F-stat. F(2, 29)	61.7769[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.072551	Equation Log-likelihood	52.0211
Akaike Info. Criterion	49.0211	Schwarz Bayesian Criterion	46.8225
DW-statistic	1.2633		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 3.9619[.047]	F(1, 28) = 3.9566[.057
B:Functional Form	CHSQ(1) = 15.0800[.000]	F(1, 28) = 24.9552[.000]
C:Normality	CHSQ(2) = .73919[.691]	Not applicable
D:Heteroscedasticity	CHSQ(1) = 2.0849[.149]	F(1, 30) = 2.0908[.159]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.13: Equation (5.16)

Ordinary Least Squares Estimation

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-1.8961	1.5460	-1.2265[.230]
LNRD	.098098	.018596	5.2754[.000]
LNKRD	.19525	.045527	4.2887[.000]
LNH	.31334	.10240	3.0600[.005]

R-Squared	.91908	R-Bar-Squared	.91041
S.E. of Regression	.033210	F-stat. F(3, 28)	106.0115[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.030882	Equation Log-likelihood	65.6869
Akaike Info. Criterion	61.6869	Schwarz Bayesian Criterion	58.7555
DW-statistic	2.1564		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .20089[.654]	F(1, 27 = .17057[.683]
B:Functional Form	CHSQ(1) = 1.3582[.244]	F(1, 27) = 1.1968[.284]
C:Normality	CHSQ(2) = 2.5797[.275]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .18119[.670]	F(1, 30) = .17084[.682]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.14: Equation (5.17)

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-7.6004	.99675	-7.6252[.000]
LNRD	.14313	.019411	7.3737[.000]
LNH	.71198	.054344	13.1012[.000]

****

R-Squared	.86593	R-Bar-Squared	.85668
S.E. of Regression	.042005	F-stat. F(2, 29)	93.6515[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.051169	Equation Log-likelihood	57.6077
Akaike Info. Criterion	54.6077	Schwarz Bayesian Criterion	52.4091
DW-statistic	1.4019		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 2.5555[.110]	F(1, 28) = 2.4301[.130]
B:Functional Form	CHSQ(1) = 3.3620[.067]	F(1, 28) = 3.2871[.081]
C:Normality	CHSQ(2) = 1.8815[.390]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .16327[.686]	F(1, 30) = .15385[.698]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.15: Equation (5.18)

Ordinary Least Squares Estimation

****

Dependent variable is LNY

32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	3.3001	1.6533	1.9960[.055]
LNKRD	.33087	.052134	6.3466[.000]
LNH	-.014457	.11293	-.12802[.899]

****

R-Squared	.83866	R-Bar-Squared	.82753
S.E. of Regression	.046080	F-stat. F(2, 29)	75.3717[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.061576	Equation Log-likelihood	54.6453
Akaike Info. Criterion	51.6453	Schwarz Bayesian Criterion	49.4467
DW-statistic	1.3852		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 2.4880[.115]	F(1, 28) = 2.3606[.136]
B:Functional Form	CHSQ(1) =13.7528[.000]	F(1, 28) =21.1033[.000]
C:Normality	CHSQ(2) = 2.2697[.321]	Not applicable
D:Heteroscedasticity	CHSQ(1) = 1.5219[.217]	F(1, 30) = 1.4980[.231]

****

A:Lagrange multiplier test of residual serial correlation

B:Ramsey's RESET test using the square of the fitted values

C:Based on a test of skewness and kurtosis of residuals

D:Based on the regression of squared residuals on squared fitted values

Table C.16: KRD5

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-6.6783	.84731	-7.8818[.000]
LNRD	.11200	.017724	6.3190[.000]
LNKRD5	.27734	.070533	3.9321[.001]
LNH	.54976	.060602	9.0717[.000]

****

R-Squared	.91362	R-Bar-Squared	.90437
S.E. of Regression	.034312	F-stat. F(3, 28)	98.7215[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.032966	Equation Log-likelihood	64.6423
Akaike Info. Criterion	60.6423	Schwarz Bayesian Criterion	57.7109
DW-statistic	1.9908		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .0036746[.952]	F(1, 27) = .0031008[.956]
B:Functional Form	CHSQ(1) = .12424[.724]	F(1, 27) = .10523[.748]
C:Normality	CHSQ(2) = .57766[.749]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .086539[.769]	F(1, 30) = .081350[.777]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.17: KRD10

Ordinary Least Squares Estimation

****

Dependent variable is LNY
32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-9.5352	1.1523	-8.2751[.000]
LNRD	.11619	.020217	5.7471[.000]
LNKRD10	.17625	.065173	2.7043[.012]
LNH	.75719	.052008	14.5591[.000]

****

R-Squared	.89370	R-Bar-Squared	.88231
S.E. of Regression	.038066	F-stat. F(3, 28)	78.4644[.000]
Mean of Dependent Variable	5.7658	S.D. of Dependent Variable	.11096
Residual Sum of Squares	.040572	Equation Log-likelihood	61.3207
Akaike Info. Criterion	57.3207	Schwarz Bayesian Criterion	54.3892
DW-statistic	1.7126		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = .66249[.416]	F(1, 27) = .57080[.456]
B:Functional Form	CHSQ(1) = .31812[.573]	F(1, 27) = .27111[.607]
C:Normality	CHSQ(2) =1.1147[.573]	Not applicable
D:Heteroscedasticity	CHSQ(1)= .99208[.319]	F(1, 30) = .95983[.335]

****

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted value

Table C.18: Equation (5.19)

Ordinary Least Squares Estimation

Dependent variable is LNF
32 observations used for estimation from 1967 to 1998

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-20.9509	6.6750	-3.1387[.004]
LNIR	1.1591	.31267	3.7070[.001]
LNRD	.30928	.085209	3.6296[.001]
LNKRD	.91583	.28216	3.2458[.003]
LNH	.31674	.51941	.60981[.547]

R-Squared	.97165	R-Bar-Squared	.96745
S.E. of Regression	.13562	F-stat. F(4, 27)	231.3679[.000]
Mean of Dependent Variable	13.1965	S.D. of Dependent Variable	.75173
Residual Sum of Squares	.49659	Equation Log-likelihood	21.2454
Akaike Info. Criterion	16.2454	Schwarz Bayesian Criterion	12.5811
DW-statistic	1.3813		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 2.5486[.110]	F(1, 26) = 2.2499[.146]
B:Functional Form	CHSQ(1) = .24533[.620]	F(1, 26) = .20087[.658]
C:Normality	CHSQ(2) = 1.9284[.381]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .77004[.380]	F(1, 30) = .73971[.397]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table C.19: Equation (5.20)

Ordinary Least Squares Estimation

****

Dependent variable is LNF

32 observations used for estimation from 1967 to 1998

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	-17.0863	2.0724	-8.2449[.000]
LNIR	1.2722	.24888	5.1116[.000]
LNRD	.27267	.059794	4.5602[.000]
LNKRD	.92190	.27880	3.3067[.003]

****

R-Squared	.97126	R-Bar-Squared	.96818
S.E. of Regression	.13409	F-stat. F(3, 28)	315.4431[.000]
Mean of Dependent Variable	13.1965	S.D. of Dependent Variable	.75173
Residual Sum of Squares	.50343	Equation Log-likelihood	21.0266
Akaike Info. Criterion	17.0266	Schwarz Bayesian Criterion	14.0951
DW-statistic	1.3110		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 3.2448[.072]	F(1, 27) = 3.0468[.092]
B:Functional Form	CHSQ(1) = .10468[.746]	F(1, 27) = .088615[.768]
C:Normality	CHSQ(2) =1.6287[.443	Not applicable
D:Heteroscedasticity	CHSQ(1) = .62555[.429]	F(1, 30)= .59814[.445]

****

A:Lagrange multiplier test of residual serial correlation

B:Ramsey's RESET test using the square of the fitted values

C:Based on a test of skewness and kurtosis of residuals

D:Based on the regression of squared residuals on squared fitted values

Appendix D: Correlation Matrix

	Fertilizer	Irrigation	R&D Expenditure	R&D knowledge Stock	Hectarage
Fertilizer	1				
Irrigation	0.97	1			
R&D Expenditure	0.19	0.05	1		
R&D Knowledge Stock	0.96	0.96	0.04	1	
Hectarage	0.82	0.88	0.27	0.86	1

Appendix E : Causality Test

Direction (Equation)	Lag (n_1 or n_2)	ESSR	ESSUR	F_s	d.f.
RD to Yield (5.21)	2	0.069	0.056	3.50**	(2,25)
	3	0.064	0.041	4.27**	(3,22)
	4	0.061	0.040	2.50*	(4,19)
Yield to RD (5.22)	2	0.920	0.830	1.32	(2,24)
	3	0.640	0.430	3.33**	(3,21)
	4	0.640	0.410	2.52*	(4,18)
KRD to Yield (5.23)	2	0.069	0.059	2.50	(2,23)
	3	0.064	0.045	3.00*	(3,20)
	4	0.061	0.043	1.80	(4,17)
Yield to KRD (5.24)	2	0.880	0.790	1.32	(2,23)
	3	0.590	0.410	3.00*	(3,20)
	4	0.580	0.390	2.09	(4,17)

Appendix F: The Relationships between Rice Yield and Incomes

Table F.1: The Relationships between Rice Yield and Household Income 1996

Ordinary Least Squares Estimation

Dependent variable is LNHOIN			
76 observations used for estimation from 1 to 76			
Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	6.6705	.59477	11.2153[.000]
LNYIELD	.40840	.099299	4.1128[.000]

R-Squared	.18606	R-Bar-Squared	.17506
S.E. of Regression	.29309	F-stat. F(1, 74)	16.9154[.000]
Mean of Dependent Variable	9.1128	S.D. of Dependent Variable	.32269
Residual Sum of Squares	6.3565	Equation Log-likelihood	-13.5518
Akaike Info. Criterion	-15.5518	Schwarz Bayesian Criterion	-17.8825
DW-statistic	1.0443		

Diagnostic Tests

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1) = 16.9365[.000]	F(1, 73) = 20.9328[.000]
B:Functional Form	CHSQ(1) = 2.3281[.127]	F(1, 73) = 2.3069[.133]
C:Normality	CHSQ(2) = 19.3439[.000]	Not applicable
D:Heteroscedasticity	CHSQ(1) = 8.6618[.003]	F(1, 74) = 9.5187[.003]

A:Lagrange multiplier test of residual serial correlation
B:Ramsey's RESET test using the square of the fitted values
C:Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values

Table F.2: The Relationships between Rice Yield and Per Capita Income 1996

```
Ordinary Least Squares Estimation
*******************************************************************************
 Dependent variable is LNPERIN
 76 observations used for estimation from    1 to   76
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONST                     4.6771            .64983             7.1975[.000]
 LNYIELD                   .52323            .10849             4.8228[.000]
*******************************************************************************
 R-Squared                     .23915   R-Bar-Squared                   .22887
 S.E. of Regression            .32022   F-stat.    F(  1,  74)   23.2598[.000]
 Mean of Dependent Variable    7.8061   S.D. of Dependent Variable      .36465
 Residual Sum of Squares       7.5878   Equation Log-likelihood       -20.2802
 Akaike Info. Criterion      -22.2802   Schwarz Bayesian Criterion    -24.6110
 DW-statistic                  1.1512
*******************************************************************************

                            Diagnostic Tests
*******************************************************************************
*    Test Statistics  *        LM Version         *         F Version         *
*******************************************************************************
*                     *                           *                           *
* A:Serial Correlation*CHSQ(   1)=  13.2737[.000]*F(   1,  73)=  15.4478[.000]*
*                     *                           *                           *
* B:Functional Form   *CHSQ(   1)=   1.4372[.231]*F(   1,  73)=   1.4071[.239]*
*                     *                           *                           *
* C:Normality         *CHSQ(   2)=  12.5423[.002]*       Not applicable       *
*                     *                           *                           *
* D:Heteroscedasticity*CHSQ(   1)=   5.4680[.019]*F(   1,  74)=   5.7369[.019]*
*******************************************************************************
   A:Lagrange multiplier test of residual serial correlation
   B:Ramsey's RESET test using the square of the fitted values
   C:Based on a test of skewness and kurtosis of residuals
   D:Based on the regression of squared residuals on squared fitted values
```

Table F.3: The Relationships between Rice Yield and Household Incomes of Farmers 1998/99

```
Ordinary Least Squares Estimation
*******************************************************************
Dependent variable is LNAGHOIN
76 observations used for estimation from    1 to   76
*******************************************************************
Regressor          Coefficient      Standard Error      T-Ratio[Prob]
CONST                6.2215            1.5775          3.9440[.000]
LNYI9899             .86605            .26357          3.2858[.002]
*******************************************************************
R-Squared                   .12732   R-Bar-Squared               .11553
S.E. of Regression            .70507  F-stat.   F( 1,  74)  10.7964[.002]
Mean of Dependent Variable  11.3979  S.D. of Dependent Variable     .74971
Residual Sum of Squares      36.7876  Equation Log-likelihood       -80.2676
Akaike Info. Criterion      -82.2676  Schwarz Bayesian Criterion   -84.5984
DW-statistic                1.7440
*******************************************************************
                  Diagnostic Tests
*******************************************************************
*   Test Statistics  *      LM Version       *       F Version        *
*******************************************************************
*                    *                       *                        *
* A:Serial Correlation*CHSQ(   1)=   1.1811[.277]*F(   1,  73)=   1.1524[.287]*
*                    *                       *                        *
* B:Functional Form   *CHSQ(   1)=   2.4914[.114]*F(   1,  73)=   2.4742[.120]*
*                    *                       *                        *
* C:Normality         *CHSQ(   2)=   6.1697[.046]*     Not applicable       *
*                    *                       *                        *
* D:Heteroscedasticity*CHSQ(   1)=   6.2148[.013]*F(   1,  74)=   6.5901[.012]*
*******************************************************************
  A:Lagrange multiplier test of residual serial correlation
  B:Ramsey's RESET test using the square of the fitted values
  C:Based on a test of skewness and kurtosis of residuals
  D:Based on the regression of squared residuals on squared fitted values
```

Table F.4: The Relationships between Rice Yield and Per Capita Incomes of Farmers 1998/99

```
Ordinary Least Squares Estimation
*******************************************************************************
 Dependent variable is LNAGPERIN
 76 observations used for estimation from    1 to   76
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONST                     3.3044            1.5514             2.1299[.037]
 LNYI9899                  1.0886            .25922             4.1996[.000]
*******************************************************************************
 R-Squared                    .19247   R-Bar-Squared                   .18155
 S.E. of Regression           .69343   F-stat.    F( 1,  74)  17.6370[.000]
 Mean of Dependent Variable   9.8112   S.D. of Dependent Variable      .76649
 Residual Sum of Squares     35.5823   Equation Log-likelihood       -79.0017
 Akaike Info. Criterion     -81.0017   Schwarz Bayesian Criterion    -83.3325
 DW-statistic                 1.8675
*******************************************************************************

                         Diagnostic Tests
*******************************************************************************
*    Test Statistics  *        LM Version          *         F Version          *
*******************************************************************************
*                     *                            *                            *
* A:Serial Correlation*CHSQ(   1)=   .28250[.595]*F(   1,  73)=   .27236[.603]*
*                     *                            *                            *
* B:Functional Form   *CHSQ(   1)=   .10247[.749]*F(   1,  73)=  .098554[.754]*
*                     *                            *                            *
* C:Normality         *CHSQ(   2)=  19.8824[.000]*       Not applicable         *
*                     *                            *                            *
* D:Heteroscedasticity*CHSQ(   1)=   2.9774[.084]*F(   1,  74)=   3.0173[.087]*
*******************************************************************************
   A:Lagrange multiplier test of residual serial correlation
   B:Ramsey's RESET test using the square of the fitted values
   C:Based on a test of skewness and kurtosis of residuals
   D:Based on the regression of squared residuals on squared fitted values
```

Appendix G: OLS Estimation for the Relationship between the Percentage of Poverty Level and Rice Yields

Table G.1: OLS for 1996 Data

Ordinary Least Squares Estimation

```
*******************************************************************************
 Dependent variable is LNP96
 74 observations used for estimation from    1 to   74
*******************************************************************************
 Regressor            Coefficient      Standard Error        T-Ratio[Prob]
 CONST                  10.1337            2.4044             4.2146[.000]
 LNY96                  -1.3670            .40186            -3.4017[.001]
*******************************************************************************
 R-Squared                      .13846   R-Bar-Squared                 .12649
 S.E. of Regression             1.1743   F-stat.    F( 1,  72)  11.5713[.001]
 Mean of Dependent Variable     1.9678   S.D. of Dependent Variable    1.2564
 Residual Sum of Squares       99.2796   Equation Log-likelihood     -115.8748
 Akaike Info. Criterion      -117.8748   Schwarz Bayesian Criterion  -120.1789
 DW-statistic                   1.2907
*******************************************************************************
                         Diagnostic Tests
*******************************************************************************
*    Test Statistics  *        LM Version        *         F Version        *
*******************************************************************************
*                     *                          *                          *
* A:Serial Correlation*CHSQ(   1)=   9.0343[.003]*F(   1,  71)=   9.8735[.002]*
*                     *                          *                          *
* B:Functional Form   *CHSQ(   1)=   .27378[.601]*F(   1,  71)=   .26366[.609]*
*                     *                          *                          *
* C:Normality         *CHSQ(   2)=  44.3198[.000]*       Not applicable     *
*                     *                          *                          *
* D:Heteroscedasticity*CHSQ(   1)=  .074715[.785]*F(   1,  72)=  .072770[.788]*
*******************************************************************************
   A:Lagrange multiplier test of residual serial correlation
   B:Ramsey's RESET test using the square of the fitted values
   C:Based on a test of skewness and kurtosis of residuals
   D:Based on the regression of squared residuals on squared fitted values
```

Table G.2: OLS for 1998 Data

```
Ordinary Least Squares Estimation
*******************************************************************
 Dependent variable is LNP98
 74 observations used for estimation from   1 to  74
*******************************************************************
 Regressor          Coefficient     Standard Error      T-Ratio[Prob]
 CONST                14.4875          2.1408            6.7672[.000]
 LNY98                -2.0675          .35932           -5.7539[.000]
*******************************************************************
 R-Squared                   .31499  R-Bar-Squared                .30547
 S.E. of Regression          .91869  F-stat.  F( 1, 72)  33.1078[.000]
 Mean of Dependent Variable  2.1846  S.D. of Dependent Variable   1.1024
 Residual Sum of Squares    60.7678  Equation Log-likelihood    -97.7123
 Akaike Info. Criterion    -99.7123  Schwarz Bayesian Criterion -102.0163
 DW-statistic                1.4852
*******************************************************************

                    Diagnostic Tests
*******************************************************************
*  Test Statistics  *      LM Version      *      F Version      *
*******************************************************************
*                    *                    *                    *
* A:Serial Correlation*CHSQ(  1)=  4.7838[.029]*F(  1, 71)=  4.9071[.030]*
*                    *                    *                    *
* B:Functional Form   *CHSQ(  1)= .0070189[.933]*F(  1, 71)= .0067350[.935]*
*                    *                    *                    *
* C:Normality         *CHSQ(  2)=  6.1733[.046]*      Not applicable      *
*                    *                    *                    *
* D:Heteroscedasticity*CHSQ(  1)=  .48592[.486]*F(  1, 72)=  .47591[.492]*
*******************************************************************
  A:Lagrange multiplier test of residual serial correlation
  B:Ramsey's RESET test using the square of the fitted values
  C:Based on a test of skewness and kurtosis of residuals
  D:Based on the regression of squared residuals on squared fitted values
```

Table G.3: OLS for Pooled Data

Ordinary Least Squares Estimation

****

Dependent variable is LNPPOOL

148 observations used for estimation from 1 to 148

****

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONST	12.0973	1.6240	7.4492[.000]
LNYPOOL	-1.6808	.27199	-6.1796[.000]

****

R-Squared	.20733	R-Bar-Squared	.20190
S.E. of Regression	1.0567	F-stat. F(1, 146)	38.1875[.000]
Mean of Dependent Variable	2.0762	S.D. of Dependent Variable	1.1829
Residual Sum of Squares	163.0407	Equation Log-likelihood	-217.1652
Akaike Info. Criterion	-219.1652	Schwarz Bayesian Criterion	-222.1624
DW-statistic	1.3669		

****

Diagnostic Tests

****

Test Statistics	LM Version	F Version
A:Serial Correlation	CHSQ(1)= 14.5278[.000]	F(1, 145)= 15.7826[.000]
B:Functional Form	CHSQ(1)= .21384[.644]	F(1, 145)= .20981[.648]
C:Normality	CHSQ(2)= 75.3542[.000]	Not applicable
D:Heteroscedasticity	CHSQ(1)= .23629[.627]	F(1, 146)= .23347[.630]

****

A:Lagrange multiplier test of residual serial correlation

B:Ramsey's RESET test using the square of the fitted values

C:Based on a test of skewness and kurtosis of residuals

D:Based on the regression of squared residuals on squared fitted values

<u>Table G.4</u>: OLS for Time-series data of Rice Yield and Percent of Poverty

Ordinary Least Squares Estimation

```
*******************************************************************************
 Dependent variable is LNPOOR
 12 observations used for estimation from    1 to   12
*******************************************************************************
 Regressor            Coefficient       Standard Error        T-Ratio[Prob]
 CONST                   23.3587            3.0760           7.5938[.000]
 LNYIELD                 -3.4791            .53022          -6.5616[.000]
*******************************************************************************
 R-Squared                    .81152   R-Bar-Squared                .79267
 S.E. of Regression           .21505   F-stat.    F( 1,  10)  43.0551[.000]
 Mean of Dependent Variable   3.1790   S.D. of Dependent Variable     .47230
 Residual Sum of Squares      .46249   Equation Log-likelihood        2.5090
 Akaike Info. Criterion       .50902   Schwarz Bayesian Criterion   .024109
 DW-statistic                 1.7130
*******************************************************************************
                          Diagnostic Tests
*******************************************************************************
*   Test Statistics  *       LM Version        *        F Version          *
*******************************************************************************
*                    *                         *                           *
* A:Serial Correlation*CHSQ(   1)=   .25160[.616]*F(   1,   9)=   .19274[.671]*
*                    *                         *                           *
* B:Functional Form  *CHSQ(   1)=   .65647[.418]*F(   1,   9)=   .52085[.489]*
*                    *                         *                           *
* C:Normality        *CHSQ(   2)=   .62959[.730]*     Not applicable       *
*                    *                         *                           *
* D:Heteroscedasticity*CHSQ(   1)=   .66898[.413]*F(   1,  10)=   .59040[.460]*
*******************************************************************************
   A:Lagrange multiplier test of residual serial correlation
   B:Ramsey's RESET test using the square of the fitted values
   C:Based on a test of skewness and kurtosis of residuals
   D:Based on the regression of squared residuals on squared fitted values
```

Appendix H: Chow Test

Chow test was applied to test whether the cross-sectional provincial data of rice yield and the percentage of poor people living in poverty in 1996 and 1998 can be pooled into the one group. Using the Residual Sum of Squares in Appendix E: Table E.1-E.3, the results of the test are as follows:

$F_c = 1.35$,

$F_{0.5}\,(2, 120) = 3.92$,

$F_{0.5}\,(2, \infty) = 3.84$.

The test result is not significant at 5% level. It can be concluded that two regressions (1996 and 1998) are not different. Two groups of data can be pooled into one group.

Appendix I: Calculated MIRR

Table I.1: MIRR for R&D Knowledge Stock with Traditional Approach

Lag Length	$VMP_{t-i}/(1.05)^i$	$VMP_{t-i}/(1.10)^i$
1	1.24	1.24
2	1.56	1.49
3	1.72	1.57
4	1.61	1.40
5	1.37	1.14
6	1.04	0.83
7	0.57	0.43
8	0.02	0.01
Total	8.14	7.11
Difference	1.03	44.51
MIRR = 10 + (5/1.03)*(7.11) = 44.51%		

Table I.2: MIRR for R&D Knowledge Stock with Zero Percent of Depreciation Rate

Lag Length	$VMP_{t-i}/(1.05)^i$	$VMP_{t-i}/(1.10)^i$
1	3.04	2.90
2	2.90	2.64
3	2.76	2.40
4	2.63	2.18
5	2.50	1.98
6	2.38	1.80
7	2.27	1.64
8	2.16	1.49
9	2.06	1.35
10	1.96	1.23
11	1.87	1.12
12	1.78	1.02
13	1.69	0.93
14	1.61	0.84
15	1.54	0.76
16	1.46	0.70
17	1.39	0.63
18	1.33	0.57
19	1.26	0.52
20	1.20	0.48
21	1.15	0.43
22	1.09	0.39
23	1.04	0.36
24	0.99	0.33
25	0.94	0.29
26	0.90	0.27
27	0.86	0.24
28	0.81	0.22
29	0.78	0.20
30	0.74	0.18
31	0.70	0.17
32	0.67	0.15
Total	49.08	30.10
Difference	18.98	17.93
MIRR = 10 + (5/18.98)*30.10 = 17.93%		

Table I.3: MIRR for R&D Knowledge Stock with Five Percent of Depreciation Rate

Lag Length	$VMP_{t-i}/(1.05)^i$	$VMP_{t-i}/(1.10)^i$
1	7.75	7.40
2	7.12	6.49
3	6.28	5.46
4	5.74	4.77
5	5.02	3.97
6	4.56	3.44
7	4.13	2.98
8	3.54	2.44
9	3.19	2.10
10	2.68	1.68
11	2.38	1.43
12	1.94	1.11
13	1.70	0.93
14	1.47	0.76
15	1.12	0.56
16	0.93	0.44
17	0.76	0.35
18	0.48	0.21
19	0.35	0.14
20	0.11	0.04
Total	60.26	45.72
Difference	14.54	25.72
MIRR = 10 + (5/14.54)*45.72 = 25.72%		

Table I.4: MIRR for R&D Knowledge Stock with Ten Percent of Depreciation Rate

Lag Length	$VMP_{t-i}/(1.05)^i$	$VMP_{t-i}/(1.10)^i$
1	7.91	7.56
2	6.70	6.10
3	5.59	4.86
4	4.94	4.10
5	3.98	3.15
6	3.10	2.34
7	2.29	1.66
8	1.56	1.08
9	1.19	0.78
10	0.57	0.36
Total	36.84	30.99
Difference	5.85	36.48
MIRR = 10 + (5/5.85)*(30.99) = 36.48%		

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